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Blistering Phenomena of Paints in Marine Environments

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SYNOPSIS

An investigation of the blistering of chlorinated-rubber-based paints, applied to mild-steel panels, immersed in *N*/2 sodium chloride has demonstrated the presence of electrolytes within the blisters. The anodic or cathodic origin of the blisters is illustrated by potential plots over a blistered surface using a silver/silver-chloride electrode. To obtain blistering it is not necessary for the anodes and cathodes to be located on the same plate.

The mechanism of blistering of paints on a steel surface immersed in sea water is discussed.

THE initial deterioration of paints in marine use frequently takes the form of blistering. The formation of blisters does not, in itself, constitute a too serious defect as long as the paint remains intact, but when the blisters break, localized corrosion and pitting occur on the bared metal. Breakage of the blisters is soon followed by more general stripping of the paint with the subsequent extension of corrosion. The extent to which blistering takes place is dependent, among other factors, upon the nature of the paint and the metal to which it is applied. Mild steel is particularly prone to paint blistering in sea water and the effects obtained on chlorinated-rubber-based paints are well defined. For these reasons, the study of the phenomenon was carried out on a chlorinated-rubber-based paint, pigmented with iron oxide, applied to mild-steel panels.

Blistering of paints in sea water has been attributed to many causes but its electrochemical nature is frequently not appreciated. Kittelberger and Elm[1, 2, 3] have indicated the rôle played by osmosis and electro-endosmosis in the formation of paint blisters in salt water. This theory postulates the transfer of water only, but the present investigation, which was carried out in 1945, has demonstrated the presence of electrolytes within the blisters, and the liquid transfer must, therefore, be reconciled with some degree of ionic permeability. In this work, the appearance and growth of blisters has been studied on panels immersed in sodium chloride solutions of approximately the same concentration as sea water. The anodic or cathodic origin of the blisters has been clearly illustrated by potential plots over a blistered surface using a silver/silver-chloride electrode.

EXPERIMENTAL PROCEDURE

Specimen panels of mild steel (approx. 15 cm. × 5 cm.) were prepared and abraded with grade 1*F* emery; pickling was avoided because of the possibility that a purely physical type of blistering may be caused by the evolution of occluded hydrogen from pickled surfaces. The paint, a chlorinated rubber-based composition pigmented with iron oxide, was applied by dipping, followed by draining and drying in a warm atmosphere. This method gave reproducible coatings of thickness varying from 0·001 in. at the top edge to 0·002 in. at the bottom. To avoid edge effects, the water line and edges of all panels were blanked off with wax. The corroding medium employed was *N*/2 sodium chloride which has approximately the same chloride concentration as sea water and is readily reproducible. The composition by weight of the chlorinated rubber paint was as follows:

60·8% volatile matter (naphtha and white spirit)
32·7% medium (chlorinated rubber)
6·5% pigment (82% Fe_2O_3, 18% siliceous matter)

The panels were placed in an almost vertical position in large beakers containing the *N*/2 sodium chloride solution and were covered with watch glasses to prevent undue evaporation and the entry of dust particles.

RESULTS OF IMMERSION TESTS

Under conditions of complete immersion in *N*/2 sodium chloride solution at room temperature, blisters became visible within 3–5 days. Growth

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Fig. 1 *Fig. 2*

Fig. 1—Blistering of a chlorinated-rubber-based paint, developed in sea water on a steel substratum

Fig. 2—Portion of steel panel showing the pitting resulting from localized attack at the seats of broken anodic blisters

progressed until some of the blisters broke and rust gathered on the broken blisters, as shown in Figs. 1 and 4. Deterioration continued until the paint had undergone extensive breakdown and stripping, leaving the panel generally corroded, with pitting localized on the areas where the blisters first broke.

The blisters that occur can be classified into two types, those which contain alkaline liquid and those which contain acidic liquid. The former, as will be shown later, are seats of cathodic action, whereas the latter, which are associated with the presence of iron salts and the eventual appearance of rust, are anodic.

Alkaline Blisters

The term alkaline blisters refers to those blisters containing an alkaline liquid; they exceeded the acidic blisters both numerically and in size, and appeared at random all over the panel. On and around these blisters, adhesion of the paint film to the metal base was poor, and this effect extended for a considerable distance from the seat of the blister. The loss of adhesion is caused by alkali creeping under the paint film. In an extreme instance, 'alkali creep' may destroy adhesion over a large area, and complete stripping of the paint will ensue. The metal underneath an alkaline blister is clean and bright and shows no evidence of corrosion.

The growth of an alkaline blister frequently occurred in a specific manner. The blister started as an active spot surrounded by a ring of small blisters, and the growth of the centre spot was much faster than that of the 'satellite' blisters which it eventually absorbed. The probable explanation of this development is as follows:

Initially, the centre active spot is a cathodic region and the 'satellite' spots are anodic. Under the influence of electrochemical action between anode and cathode, the centre spot builds up a concentration of alkali, which undermines the adhesion of the paint in the vicinity of this cathode and commences to creep outwards underneath the film until it finally enters the anodic 'satellites' and suppresses the anodic reaction. In consequence, the growth of the 'satellites' stops while that of the centre spot will proceed under the influence of a more distant anodic region. If the paint film from such a region is stripped, a ring of rust spots is seen on the underside of the film where the 'satellites' were located, indicating that these, at some stage, were anodic areas.

Although no corrosion takes place under cathodic blisters, they are a serious danger, for they contain sufficient alkali to undermine paint adhesion over an extensive area, and should this area of coating strip off, as it normally does, an equally large area of steel is bared to the corrosive environment.

Acidic Blisters

The number of acidic blisters appearing on a panel was always considerably less than the number of alkaline blisters. They did not develop to any appreciable extent and had a brittle skin, which broke at an early age. The early breaking of anodic blisters is probably one of the reasons for their paucity in comparison to the many cathodic ones, for when the paint film of an acidic blister has broken, the anode underneath can assimilate a far greater current than a corresponding alkaline blister, which still has a film of comparatively high electrical resistance covering it. In other words, one broken anodic blister is capable of accepting the current from many cathodic blisters, and, as blistering develops, there is no increase in the number of anodic blisters, but the rate of attack at the anodes increases. This leads to intensive localized pitting (*see* Fig. 2) which is the most dangerous form of corrosion.

The acidic blisters tend to be located at the edges of the panel rather than in the centre, but when the paint begins to show signs of a general breakdown, acidic blisters are likely to appear all over the panel. It is probable that, initially, anodic areas are formed at random on the panel, but that those in the centre of the panel are suppressed, before they attain any size, by the alkali creeping from the cathodic areas.

MEASUREMENT OF CONCENTRATION OF ALKALI IN CATHODIC BLISTERS

Tests with indicator paper showed that the alkali in cathodic blisters has a *p*H of at least 13. Because of the small amount of liquid available from a fully developed blister (approx. 0·005–0·010 ml.) an estimation of the concentration of alkali by titration methods would require laborious experimental technique. Since the plates were blistered in sodium chloride solution, the alkali in the blisters must be sodium hydroxide, and an indirect method of estimation was employed which depended upon the variation of the refractive index of sodium hydroxide solutions with the concentration. A high degree

of accuracy cannot be expected from the method because of the presence of small amounts of other solutes in the blister liquid which may slightly affect the refractive index. Tests, however, have revealed that only a trace of sodium chloride was present in the blister liquid.

The refractive indices of sodium hydroxide solutions, up to twice normal, were measured at 18° C. using an Abbé refractometer. The relation between the change in the refractive index ($\Delta\eta$) from an infinitely dilute solution and the concentration of alkali (C) in equivalents/litre is shown graphically in Fig. 3. The infinitely dilute solution was taken as $N/1000$ sodium hydroxide whose refractive index at 18° C. is 1·3334. This relation is approximately linear and for the purpose of the experiment is shown as such. The most likely contaminant will be sodium chloride, and a theoretical curve[4] for this substance has been included. The two graphs are similar and therefore small amounts of sodium chloride will have a negligible effect on the refractive index of the strong alkaline solution.

The refractive indices of samples extracted from the blisters, using a fine capillary tube, ranged from 1·3480 to 1·3490 ($\Delta\eta = 0{\cdot}015$–$0{\cdot}016$), which corresponds to an alkali concentration of approx. $1{\cdot}5N$. This figure is surprisingly high and throws some light on the reason why the blister liquid is so effective in destroying the adhesion of the paint.

ELECTROCHEMICAL NATURE OF BLISTERING PHENOMENA

The usual cathodic process in corrosion in neutral electrolytes is the ionization of oxygen with the production of hydroxyl ions. The precise reaction envisaged by Tomashoff[5] is as follows :

$$O_2 + 2H_2O + 2e \rightarrow H_2O_2 + 2(OH^-)$$
$$H_2O_2 + 2e \rightarrow 2(OH^-)$$

Correspondingly, the anodic reaction involves the production of metal ions and reduction in the pH of the anolyte.

$$Fe \rightarrow Fe^{++} + 2e$$
$$Fe^{++} + 2H_2O \rightleftharpoons Fe(OH)_2\downarrow + 2H^+$$

The proof of the electrolytic nature of blistering must lie in demonstrating that electrical currents flow between blisters. Electric currents flowing through a solution necessarily imply a potential gradient in that solution and the greater the resistivity of the solution the greater is the potential gradient. The potential at any point of a solution may be determined relative to an arbitrary standard by the use of a suitable electrode ; for sodium chloride solutions the reversible Ag/AgCl electrode gives good results and an equipotential diagram of the solution immediately over a blistering panel can be determined.

The potential gradients corresponding to the corrosion currrents found over a corroding panel in an electrolyte as conductive as $N/2$ sodium chloride are very small and not readily detectable by a reversible Ag/AgCl electrode. By reducing the concentration of sodium chloride in solution, the increased resistivity, giving increased potential differences, renders the gradients more easily detectable. For this reason the electrochemical examination was

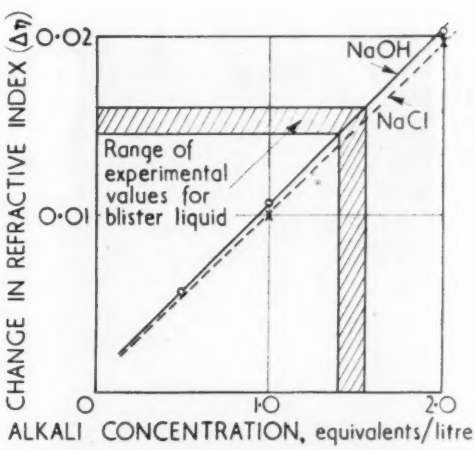


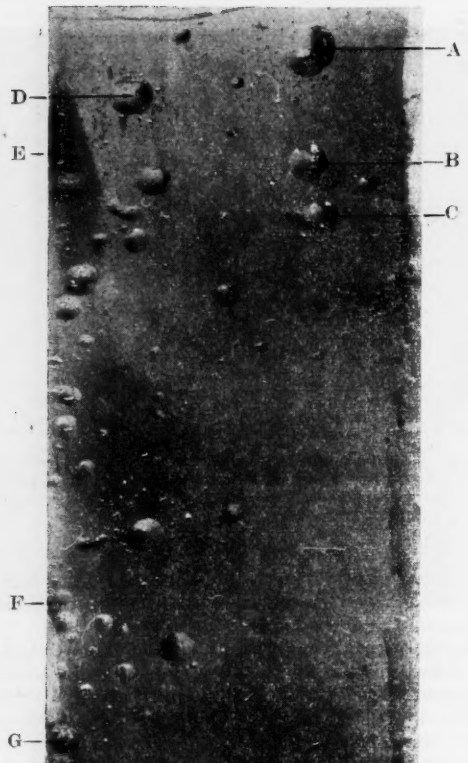
Fig. 3—Change of refractive index of sodium hydroxide and sodium chloride solutions, with concentration. The experimental value for blister liquid indicates a concentraton of about $1{\cdot}5N$

carried out in approx. $N/1000$ sodium chloride, whilst the actual development of blistering was carried out in $N/2$ sodium chloride to produce the effects previously described.

A steel panel prepared and painted as described on p. 353 was immersed in $N/2$ sodium chloride solution for about three weeks. Well-defined alkaline blisters and several acidic blisters, evidenced by the associated rust, were visible. The panel was then removed, washed, and left to stand for several hours in a shallow dish containing $N/1000$ sodium chloride.

The Ag/AgCl electrodes were formed by electrolytically depositing silver chloride on silver wire in decinormal hydrochloric acid. The washed electrodes were immersed in $N/1000$ sodium chloride. Several electrodes were formed and their potential measured at intervals against a saturated calomel half cell. Two electrodes, whose potentials never differed by more than 1 mV., were chosen for the experiment.

The potentials of the electrolyte over the panel were explored using the two similar Ag/AgCl electrodes. One electrode, fixed in a corner of the shallow tank, served as a reference electrode ; the other was mounted on a frame capable of transverse and longitudinal movement. The moving electrode was held in a narrow glass tube drawn off to a fine section, the point of which traversed the panel about 1 mm. from the paint surface. The difference in potential between the two electrodes was measured on a valve potentiometer. Figure 5 shows an experimental equipotential diagram obtained over the panel shown in Fig. 4. The equipotential plot shown in Fig. 5 does not give a true quantitative picture of the currents flowing since the measurements were taken in one plane only. True current-density figures may be obtained by exploring two planes at right angles to one another. Since, however, the object of this work was merely to detect and to illustrate the current flowing between blisters, the single electrode method only was employed. High positive values are associated with the rust spots, which are the seats of acidic blisters, and negative values occur in the regions



A, *B*, *C*, and *D*—alkaline blisters
E, *F*, and *G*—acidic blisters surrounded by rust

Fig. 4—Alkaline and acidic blisters on a steel panel

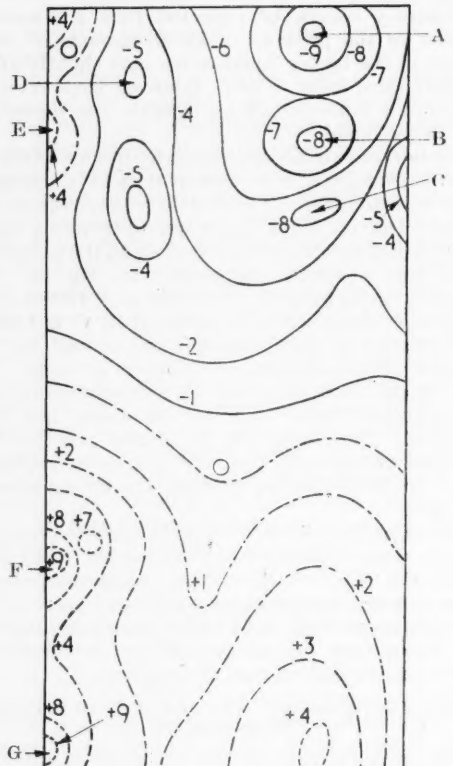


Fig. 5—Equipotential contour diagram of the panel in Fig. 4, showing the negative and positive high-spots. (Figures are in millivolts)

of alkaline blisters. The three blisters *A*, *B*, and *C* marked in Fig. 4 are clearly defined in the equipotential diagram; other alkaline blisters near the rust areas are not so clear, but this is to be expected because of the preponderating effect of the nearby highly positive fields. It is concluded, therefore, that blistering is largely an electrochemical phenomenon and that acidic blisters are evidence of anodic regions, while alkaline blisters are seats of cathodic action.

ACCELERATED BLISTERING BY IMPOSED E.M.F.

To obtain blistering phenomena it is not necessary for the anodes and cathodes to be located on the same plate. This may be demonstrated by immersing two similarly painted panels in *N*/2 sodium chloride and connecting them to an external source of E.M.F. supplying approx. 0·2 V. The cathodic panel blistered much more rapidly than it would do if immersed by itself and it exhibited nothing but alkaline blisters. The anodic panel displayed anodic blisters and also a proportion of alkaline blisters. The absence of anodic blisters on the cathodic panel and the presence of both types on the anodic one is a feature of the difference in polarization characteristics. Cathodic polarization is more pronounced and hence the cathodic current density is more uniform, thus polarizing the whole of the cathode surface to approximately the same potential and consequently preventing the development of any anodic tendency. Anodic polarization is slight and the active anodes are small in area; thus the entire anodic effect is localized and the anodic panel may develop cathodic regions.

Two similar panels, such as were used in the previous experiment, were immersed in *N*/2 sodium chloride solution and were connected to an external source of E.M.F. (0·2 V.) until blisters began to appear on the cathode; the external E.M.F. was then removed and the panels were connected together directly. The panel that was cathodic under the influence of the E.M.F. remained cathodic and the original anode was still anodic. Blistering continued at a considerably faster rate than on unconnected specimens. This means that in practice when blistering has been induced by some external factor, it is likely to continue at an accelerated rate, even although that external influence is removed.

Accelerated blistering by imposing an E.M.F. is frequent when painted dissimilar metals are in contact. For this reason, attempts to reduce bi-metallic corrosion in sea water by painting the cathode are

frequently unsuccessful, as the paint film soon blisters and this is followed by the more general breakdown caused by excessive production of alkali.

MECHANISM OF BLISTERING

These results suggest that the mechanism of the blistering of paints on a steel surface in sea water probably develops along the following lines :

(1) At points of weakness or imperfection in the paint film, water penetrates and makes contact with the underlying metal. This phase of the process is concerned with permeability factors only. The issues which determine whether this location is now to become a cathode or an anode are dependent upon many variables, namely, the composition, structure, and surface condition of the underlying metal and the environmental conditions which persist in the electrolyte immediately over this area.

(2) If the location should tend to become a cathode then the water that has permeated the paint film will contain the normal amount of dissolved oxygen and will undergo ionization to hydroxyl ions. This is the criterion of the cathodic reaction. The production of excess hydroxyl ions creates an electronegative space-charge effect which, as well as the normal cathodic field, causes sodium ions to migrate through the film. In addition, because the area is a cathode, more water with its dissolved oxygen is transferred through the film under the influence of electro-endosmotic forces. This causes the raising of a blister and the ingress of more oxygen, which maintains the cathode, and, in consequence, the production of a further excess of hydroxyl ions ; and so the process continues. The concentration of alkali within the blister continues to rise, and it is probable that some of the hydroxyl ions formed diffuse out into the bulk of the electrolyte, but so long as the production of hydroxyl ions is maintained at a rate relatively higher than the diffusion rate, the concentration of alkali increases. The process explains the initiation, growth, and alkali content of cathodic blisters. Degradation which follows may be brought about either by the rupture of the blister under tension caused by loss of physical properties of the paint film owing to the excess alkali, and/or by the destruction of adhesion over a large area surrounding the blister, also caused by the presence of alkali. This latter effect leads to large-scale flaking.

(3) The development of an anodic blister commences in the same way as that of a cathodic blister, *i.e.*, by the permeation of water through points of weakness but, because of environment, less oxygen is probably available.

The anodic reaction involves the ionization of the metal, or in the case of a steel panel the production of ferrous ions, and these may react with water to give hydrogen ions, thus giving rise to the acidity which distinguishes these areas. The availability of oxygen at the anode is restricted by the oxidation of these ferrous ions to ferric hydroxide and there is, therefore, no tendency for conversion to a cathode, even if the original defect in the paint film becomes more pronounced.

The build-up of a concentration of anions within the blister is rapid since the anodic current density is normally higher than the cathodic current density. Chlorine ions migrate through the film under the influence of the electropositive field. Anodic blisters never attain any size and the amount of water that is transferred to the inside is very small : this transference is probably induced by osmotic pressures caused by the high rate of build-up of ferrous ions. Occasionally, what appears to be a large anodic blister covered with rust is encountered, but it is likely that such a blister in the film was orginally cathodic and was ruptured in the process of its normal growth. The hydroxyl ions, which had previously been formed, would then diffuse away and be replaced by chloride ; the bared metal would then become anodic.

The presence of acid in the anodic blisters causes the film to become hard and brittle, and rupture or cracking take place very early, in many instances even before any appreciable blister-like deformation of the paint film has taken place. Rust soon appears in these regions because of the normal oxidation and precipitation of ferrous ions.

EFFECTS OF OTHER PAINTS

In practice, the effects obtained with other types of marine paints are similar to those already described for chlorinated rubber, but are not so pronounced. The degree of permeability of the paint film appears to determine the precise nature of the attack ; the more permeable the film the smaller are the blisters, since a permeable film will not retain the ions produced electrolytically, and osmotic or electro-endosmotic effects do not ensue. Furthermore, there will be a higher proportion of anodic areas on permeable media, since the effect of alkali ' creep ' will not be so apparent with lower concentrations of alkali. The overall effect leads to a more general form of breakdown. On the other hand, with paints based on highly impermeable media, such as chlorinated rubber, the results tend to be localized and give a ' pitting ' form of attack. As previously described, blisters on this type of composition only occur at weaknesses or imperfections in the film, and if care is exercised to ensure an adequate thickness of paint coating over all surfaces, preferably as several coats, the risk of failure by blistering is greatly reduced. For permeable films the answer is not quite so obvious, and it is difficult even with adequate thickness to eradicate the effect entirely.

Acknowledgment

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Significance of Equilibrium and Reaction Rate in the Blast-Furnace Process

By J. B. Austin, Ch.E., Ph.D

SYNOPSIS

The blast-furnace process comprises a series of reactions, which are delicately balanced so that it operates at a substantially steady state. On the basis that all the reduction is 'indirect,' it is possible to set up a thermodynamically ideal, isothermal process, operating at minimum consumption of carbon. Comparison of this minimum with the amount of carbon required as fuel indicates that in a furnace producing the common grades of iron from Mesabi ore the requirement for carbon is determined primarily by the need for a reducing agent. The reaction between slag and metal in the hearth is not at equilibrium in respect to sulphur. The operation of the furnace is influenced by the effective rate of a number of reactions, such as the reduction of iron oxide, the dissociation of limestone or moisture, and the 'solution' of carbon.

Introduction

THE purpose of this paper is to review, in general terms, some of the ways in which physico-chemical methods are useful in investigating the blast-furnace process. The coverage is admittedly incomplete and many limitations of practical operation have, of necessity, been overlooked. Moreover, much that is in this paper has already been stated by others, although perhaps in a somewhat different form, but repetition is justified because the fundamental rôle of chemical equilibrium and reaction rate in the blast-furnace process has not received the recognition it deserves.

When the physical chemist opens his tool chest he finds his implements arranged in two main compartments, one labelled 'Equilibrium,' the other 'Reaction Rate.' Each compartment contains powerful instruments but he is usually inclined to start with something from the 'equilibrium' set, because these tools are in general better developed, because he has had more experience in using them, and because they often aid him in using equipment from the other compartment. If the problem is relatively simple he may need only a few tools, but when he approaches a process as complex as that which occurs in the blast-furnace, he has need for virtually all the implements at his command, and even these will not always suffice.

The blast-furnace process, although carried out in deceptively simple apparatus is, in fact, exceedingly intricate. It comprises a whole series of reactions which are delicately balanced so that the process may operate at a substantially steady state. In this respect it is somewhat analogous to the human body, although the resemblance is obscured by the fact that the limbs have become atrophied and lost, the brain has been transferred to the furnace operator, and certain parts of the nervous system to a control panel, leaving a greatly enlarged alimentary canal and circulatory system.

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One unfortunate characteristic of such a complex steady-state process, whether it be the blast-furnace or the human body, is that when it is disturbed it is difficult to predict in any detail what the new steady state will be. And just as the physician administering a new drug must be on guard against unforeseen side reactions, so the blast-furnace operator must be prepared for unexpected results when he alters his practice in any way. For example, from certain points of view, enriching the blast with oxygen appears to be advantageous, yet those who have tried it find that more than a moderate amount of such medication begins to produce what is politely referred to as discomfort in the patient.

In general the devices in the 'equilibrium' compartment enable us to construct maps, which show our present position and indicate the directions in which we may move to achieve certain desired ends. They also enable us to estimate maximum yields and to determine certain limits beyond which we cannot hope to go.

Information of this sort has such obvious utility in dealing with the blast-furnace that it seems strange that these tools, many of which have been available for years, have not been a more significant factor in developing blast-furnace practice. Not that their significance has gone unrecognized, for many investigators have called attention to them, but until fairly recently these prophets were all too often 'crying in the wilderness.'

Historical

One of the first to appreciate the power of what are now known as physical chemical methods, was Sir Lothian Bell who found time in a very busy commercial life to carry out some remarkable investigations. He was among the first to apply the First Law of Thermodynamics to the blast-furnace and to devise a reasonably successful heat balance for it.

Some time later, J. E. Johnson[1] recognized that although the blast-furnace needs a certain quantity of heat it is essential that some part of this heat have the proper quality, *i.e.*, the proper temperature. More specifically, he pointed out the necessity of distinguishing between the total heat required and that needed

in the hearth and bosh zones. This application of the Second Law of Thermodynamics was a promising start, but the blast-furnace process is so complex that little progress has been made in elaborating this concept.

Judging from published records, however, one of the first to recognize the significance of equilibrium in the operation of the blast-furnace process was Le Chatelier who, as early as 1888,[2] wrote :

> " It is known that in the blast-furnace, iron oxide is reduced by means of carbon monoxide, according to the reaction
>
> $$Fe_2O_3 + 3CO = 2Fe + 3CO_2$$
>
> but the gas leaving the stack contains a considerable proportion of carbon monoxide, which thus carries away a significant quantity of unutilized heat. Because this incomplete reaction was thought to be due to insufficiently prolonged contact between carbon monoxide and the iron ore, the dimensions of the furnaces have been increased. But the proportion of carbon monoxide escaping has not decreased, thus demonstrating by an experiment costing several hundred thousand francs, that the reduction of iron oxide by carbon monoxide is a limited reaction. Acquaintance with the laws of chemical equilibrium would have permitted the same conclusion to be reached more rapidly and more economically."

This quotation, with its reference to the composition of the top gas, raises two questions which can be answered, in part at least, by direct use of equilibrium calculations. Firstly, is the consumption of coke determined by the need for carbon as fuel or as a reducing agent, and secondly, what is the minimum amount of carbon required to produce a ton of iron in the blast-furnace ?

An attempt to answer these questions is described in detail in an earlier paper[3] on the efficiency of the blast-furnace process, but since some parts of that discussion are pertinent to this paper they are reviewed here.

CONSUMPTION OF CARBON

Carbon as a Reducing Agent

One way to answer these questions is to calculate the minimum amount of carbon required as a reducing agent and then to compare this amount with that required to provide the necessary heat. But what is the minimum amount of carbon required for reduction ? One may write the stoichiometric relation

$$2Fe_2O_3 + 3C = 4Fe + 3CO_2 \quad \ldots\ldots\ldots\ldots (1)$$

from which it would appear that 2240 lb. of iron can be produced with only 360 lb. of carbon, although no one believes that this reaction, as written, takes place in the blast-furnace.

The reactions which are often assumed to occur are :

$$Fe_2O_3 + 3C = 2Fe + 3CO \quad \ldots\ldots\ldots\ldots (2)$$
$$Fe_2O_3 + 3CO = 2Fe + 3CO_2 \quad \ldots\ldots\ldots\ldots (3)$$

If these equations are valid, then it takes 720 lb. of carbon, either as coke or as carbon monoxide, to produce a ton of iron. Reaction 2 corresponds to ' direct ' reduction and may occur to a limited extent, for instance in the pool of molten iron in the hearth, if unreduced ferric oxide persists to that level. To this limited extent, the equation gives the correct amount of carbon consumed. The forward reaction

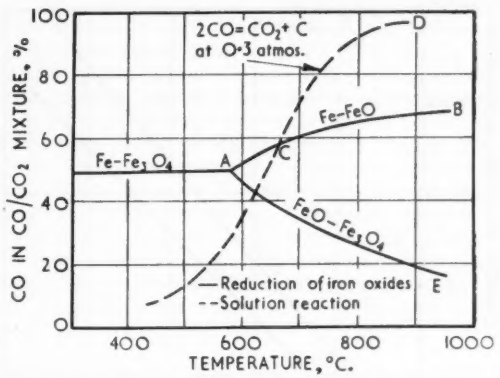

Fig. 1—Equilibrium concentration of CO in reduction of iron oxides and in solution reaction

is, however, strongly endothermic and needs a considerably greater supply of heat to keep it going.

In the blast-furnace, however, most of the reduction is represented by reaction 3, *i.e.*, by ' indirect reduction.' The equation as written is misleading because it fails to show that all the carbon monoxide is not available for reduction : because of equilibrium requirements in this system, some considerable fraction of it is required to maintain the necessary excess of carbon monoxide and to prevent the reoxidation of the iron produced. The composition of equilibrium mixtures of the oxides of carbon over the oxides of iron, which is presented as a function of temperature in Fig. 1, must be taken into account. In accordance with phase-rule requirements, there is at each temperature a fixed composition of gas in equilibrium with each pair of iron oxides. Because the amount of carbon monoxide present at equilibrium over Fe_2O_3 and Fe_3O_4 is only a small fraction of 1%, data for this pair of oxides have been omitted in Fig. 1.

Curve *AB* shows that if a limited volume of pure carbon monoxide is brought in contact with a mixture of ferrous oxide and iron at 900° C. (1650° F.), iron oxide is reduced until at equilibrium the gas contains 68% of carbon monoxide and 32% of carbon dioxide, and the reaction ceases. Thus at this temperature only about one-third of the carbon monoxide is available for reduction, the remainder being required to prevent a reversal of the reaction. Conversely, if one starts with pure carbon dioxide, iron is oxidized until the gas has attained this same limiting composition.

Curves *AE* in Fig. 1 show that at this same temperature the equilibrium mixture over FeO and Fe_3O_4 contains 18% of CO and 82% of CO_2, whereas that over Fe_3O_4 and Fe_2O_3 contains only a small fraction of 1% of CO. This means that in terms of carbon consumed the most costly step in reducing Fe_2O_3 to iron is the reduction of ferrous oxide. It should also be noted that the equilibrium mixture for the reduction of ferrous oxide contains more than enough residual carbon monoxide to meet equilibrium requirements in the reduction of Fe_3O_4, and, in turn, the equilibrium mixture for this reaction is strongly reducing to Fe_2O_3.

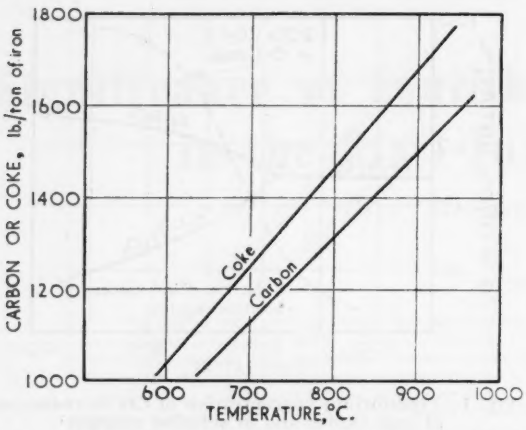

Fig. 2—Effect of temperature on amount of coke or carbon required in 'ideal' blast-furnace working under equilibrium conditions

Carbon Requirements of the Ideal Process

The above conclusions enable us to consider an ideal process, operating at constant temperature and achieving equilibrium in each step, which will produce iron from hematite by indirect reduction with a minimum consumption of carbon. Such a process comprises three heated chambers, all at the same temperature, and so connected that gas can be passed from one end to another as desired. These chambers each contain an amount of FeO, Fe_3O_4, or Fe_2O_3 respectively, equivalent to one ton of iron.

To operate the process at 900° C. (1650° F.) an amount of pure CO sufficient to reduce all the oxide is added to the chamber containing FeO. When equilibrium is attained, the gas, now containing 68% of CO, is passed into the second chamber where it reduces the Fe_3O_4 to FeO. When this step has been completed the residual gas, which now contains rather more than 18% of CO, is passed into the third chamber in which the Fe_2O_3 is reduced to Fe_3O_4. In effect, a ton of iron has been produced from Fe_2O_3 at an expenditure of carbon which is controlled by the reaction which occurs in the first chamber and which may be written

$$FeO + 3{\cdot}1\,CO = Fe + CO_2 + 2{\cdot}1\,CO \text{ (at 900° C. or 1650° F.)} \quad ...(4)$$

From this relation we calculate that, if all the reduction is indirect, about 1500 lb. of carbon is required to produce 2240 lb. of iron. Although this process represents equilibrium at each step it does not achieve a steady state analogous to that attained in the blast-furnace.

If this process is operated at some lower temperature at which the equilibrium concentration is more favourable, less carbon is required, as illustrated in Fig. 2. In this diagram the lower curve shows, as a function of temperature, the minimum amount of carbon required for indirect reduction and the upper curve gives the minimum amount of coke required, assuming the coke to contain 90% of fixed carbon.

Two significant conclusions can be drawn from this diagram : (*a*) From the standpoint of consumption of carbon, the lower the effective temperature of reduction the greater is the efficiency, and (*b*) at any temperature at which the rate of reduction proceeds rapidly the amount of carbon required is always greater than that indicated by the simple stoichiometric equations for either indirect or direct reduction (reactions 2 and 3). It can also be deduced that if enough heat is available to support direct reduction, the coke rate can be lessened by increasing the amount of such reduction. Thus if reaction 2 occurs in the hearth, the carbon monoxide evolved is available, in part, for further reduction in the shaft, so that the amount of carbon required is less than the 720 lb. indicated by reaction 2 but is greater than the 360 lb. indicated by reaction 1.

Heat Liberated by Combustion

We must now determine whether the heat liberated by combustion of the amount of carbon required as a chemical reagent, as indicated by the data in Fig. 2, is sufficient to meet the thermal requirements of the process. Without going into the details of heat balances, it suffices to state that, according to Mathesius,[4] a blast-furnace producing the common grades of pig iron from Mesabi ores requires about 13,000,000 B.Th.U./ton. The heat supplied by the hot blast is approx. 2,000,000 B.Th.U./ton of iron produced, hence, if the heat liberated by combustion of carbon, when it is burned to give a mixture of CO and CO_2 corresponding to that over iron and FeO, is 11,000,000 B.Th.U. or greater, it may be concluded that coke consumption is determined mainly by the need for carbon as a reducing agent. When such calculations are made on the basis that reduction takes place at 815° C. (1500° F.), the heat generated is between 11,000,000 and 12,000,000 B.Th.U./lb., hence the heat supplied by the combustion of coke to produce the necessary reducing gas is very nearly enough to supply the needs of the process and under most conditions the hot blast can make up the deficit and maintain a satisfactory operating heat balance. Indeed, there appears to be some extra heat which can be used to support direct reduction in the hearth.

These rather rough calculations indicate, therefore, that, for the production of basic iron from Mesabi ores, the amount of carbon needed is determined by the requirement for carbon as a reducing agent. This conclusion may not be valid, however, for a furnace practice for which the heat balance is different, *e.g.*, in the production of ferromanganese.

The relatively close agreement between the heat supplied by combustion of the carbon required to give the necessary excess of carbon monoxide and the heat required for the furnace as a whole shows, in accord with practical experience, that the final balance is obtained by blast-temperature regulation. It also indicates the high degree to which the management and operation of the blast-furnace have been developed, for unless there is a proper selection of the charge, particularly of the fuel, a proper furnace design and proper operating practice, and a proper rate of driving, the difference between the heat requirements of hearth and stack zones is so great that a complete balance cannot be achieved by blast-temperature regulation alone. The fact that

such regulation is possible is a tribute to the skill of the blast-furnace operator.

EQUILIBRIUM IN THE BLAST-FURNACE

The data in Fig. 2 also suggest that in many modern blast-furnaces using coke at the rate of 1600–1800 lb./ton the reduction reactions are operating close to equilibrium and therefore at a high carbon-consumption efficiency. This conclusion is supported by Kinney's measurements[5] of the composition of the gas at different levels in the stock column of a commercial furnace which show that the ratio CO/CO_2 is not far from that required for equilibrium. It is also fair to infer that in most furnaces some significant proportion of the reduction must be carried out by carbon directly.

A comparison of the calculations of Gumz,[6] who used a somewhat different approach, with measurements reported by Wiberg shows that, apart from the methane equilibrium and a few hearth reactions, "the equilibria in the blast-furnace are complete."

Oxygen in the Blast

The conclusions as to the rôle of equilibrium in blast-furnace operation also have a bearing on the advantages, if any, to be gained by enriching the blast with oxygen. So far as coke consumption is concerned, these advantages appear to be small if equilibrium is approached in the reduction reactions. As oxygen itself does not enter into the reduction it is difficult to see how the performance of a furnace working close to equilibrium conditions can be significantly improved by a higher concentration of oxygen in the blast. The only way oxygen can affect the process is by providing a higher combustion temperature and by giving a better control of the hearth heat, but these adjustments can usually be made more simply by changing the blast-temperature. If, on the other hand, the furnace were making ferromanganese or ferrosilicon, which requires a high hearth temperature and a large heat supply, a blast enriched in oxygen might be helpful, if economically practicable. This matter has been considered in more detail by Gumz[7] who concludes, largely on the basis of German experiments, that coke consumption decreases as the oxygen content of the blast is increased to about 30% but increases with further enrichment. There is, however, an increase in the heating value of the top gas.

Slag–Metal Reaction

Other obvious applications of equilibrium in the blast-furnace process are in the adjustment of composition within the slag and the reaction between slag and metal. In the absence of direct measurements, it was a common assumption for many years that the slag and metal in the hearth were substantially at equilibrium with respect to concentration of sulphur, silicon, and manganese. Recent work by Hatch and Chipman[8] has, however, indicated that pure slags approximating to the composition of those in the blast-furnace are capable of absorbing much greater quantities of sulphur than do the slags in ordinary furnace operation. The discrepancy is, indeed, so great that one is tempted to withhold complete acceptance of their data until they are confirmed by other investigations. E. W. Filer and L. S. Darken,[9] working along analogous lines in the author's laboratory, have reheated samples of blast-furnace slag and metal taken simultaneously from commercial blast-furnaces. Their preliminary results confirm the conclusion that, with regard to sulphur, equilibrium is, in fact, not attained, but they suggest that the approach to equilibrium is closer than one would infer from the work of Hatch and Chipman. A definite answer to this question is of great significance, particularly to operators in the United States who are confronted with increasing sulphur contents in their raw materials and fuels.

Refractories

Another item in furnace operation on which equilibrium is an important consideration is that of refractories. Phase-equilibrium diagrams, when they are available, are an invaluable aid in interpreting the behaviour of refractories and in suggesting means of improving them. A furnace at the United States Steel Corporation recently suffered an iron breakout through the fireclay brickwork of the hearth. Examination of damaged brick revealed an absorption of alkali with consequent disruption of the structure of the refractory. Interpretation of these observations on the basis of a phase diagram made clear what had been happening and suggested possible remedies. Experience in the United States with carbon refractories has been somewhat less fortunate than experience in the United Kingdom. The apparent cause of some of the difficulties has been the destruction of the bond by gases of high oxygen potential, either water vapour or carbon dioxide. A knowledge of equilibrium conditions in the systems carbon–oxygen, or carbon–oxygen–hydrogen, has been helpful in explaining these failures and in indicating promising directions in which to seek a solution.

REACTION RATE IN THE BLAST-FURNACE

As has already been mentioned, the blast-furnace process is essentially a continuous, steady-state operation in which there is a delicate balance among a great many reactions so that if one changes one factor, even slightly, it is difficult to predict the new steady state which will result. Moreover, one cannot with certainty extrapolate results obtained with a specific set of conditions in a particular furnace to operation under other circumstances.

Rate considerations of this kind have a bearing on the difficulties encountered in studying the blast-furnace process on a pilot-plant scale. To achieve similitude in such a model at least three processes must be considered, namely, the rate flow of solid granular material, the flow of gas, and the rate of heat transfer both up the stack and through the walls. Unfortunately, the laws of similarity are different in each case, so that perfect representation can never be achieved. Useful information can, however, be obtained from a pilot-scale furnace, since investigations such as those of Saunders, Butler, and Tweedy,[10] are unquestionably fruitful, but conclusions drawn from such experiments should be accepted only after careful scrutiny.

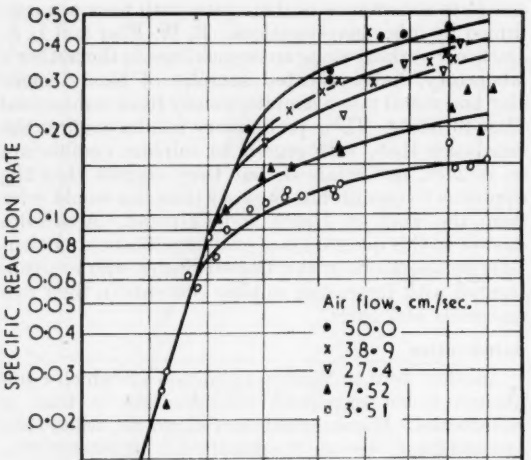

Fig. 3—Combustion rates of carbon in air (Tu, Davis, and Hottel[11])

In considering the rate of a chemical process it is helpful to distinguish between two general types of variable, one essentially chemical, the other physical. The first group comprises those factors which influence the rate of chemical interaction between the reactants, notably temperature, pressure, composition, and the presence of a catalysing surface. The second group comprises those factors which affect the rate at which one reactant is transported to another, *i.e.*, the rate of mixing in a homogeneous reaction or the rate of mass transfer of a fluid to a solid reactant in a heterogeneous reaction. Among the variables in this group are : turbulence of fluid flow, linear velocity, pressure drop, particle size, and specific surface of solid reagents. Diffusion rates may also have a significant influence and it is sometimes difficult to know whether to classify them as physical or chemical factors. The separation of such variables is never easy and in the blast-furnace it becomes extremely difficult. Indeed, our lack of understanding of the rate of combustion and reduction reactions stems in large part from this difficulty.

Rate of Combustion of Carbon

A pertinent illustration is the rate of combustion of carbon in air which has been investigated by Tu, Davis, and Hottel[11] ; the results are presented in part in Fig. 3. These data show that at temperatures up to about 1100° K. the rate of combustion is essentially controlled by the velocity of chemical reaction and is not influenced by the rate of flow of air. At higher temperatures, the velocity of reaction becomes so great that the controlling factor is the rate at which the reactants are brought together. One of the most interesting questions of overall rate which, in spite of much attention, remains unanswered is : What is the factor which essentially limits the rate of production in a blast-furnace ? Studies of the rate of combustion of carbon, such as that illustrated in Fig. 3, make it necessary to discard the once-prevalent view that rate of production is controlled primarily by the rate at which coke can be burned at the tuyere.

Some problems in the blast-furnace, such as the rate of reduction of solid particles of iron oxide, are best discussed in terms of specific examples. There is a great difference in the speed with which different ores reduce : in general, hematite reduces relatively easily, magnetite more slowly, and wüstite much more slowly. This may be because of a difference in structure, such as a difference in porosity, or because of a difference in heat transfer. Wild and Saunders[12] have recently suggested that it may be in large part because of the former.

Another significant question which involves consideration of both equilibrium and rate is the effect of the so-called solution reaction

$$2CO \rightarrow CO_2 + C \qquad \text{.....(5)}$$

Direct measurements show that at low temperatures this reaction proceeds in the forward direction with the formation of carbon and carbon dioxide but that as the temperature increases CO becomes increasingly stable (*see* broken curve, Fig. 1). On the other hand, the reaction velocity is low at low temperatures but increases with temperature. In consequence, maximum formation of carbon occurs in the medium temperature range, *i.e.*, approx. 550° C. (or about 1000° F.).

Catalysing Surface

The action of certain surfaces, notably those of iron and its oxides, in catalysing reaction (5) has a bearing on the so-called carbon disintegration of blast-furnace refractories. Thus, if the refractory brick contains, as it often does, particles of iron oxide of high activity, carbon is deposited around these particles with consequent destruction of the refractory. One solution is to fire the brick in such a way that these iron-bearing spots are converted to silicates, or at least to a less active form of oxide. But there are strong indications that the activity of such particles may be greatly diminished through poisoning by traces of impurity in the carbon monoxide. For example, investigations by Shea[13] suggest that a small amount of sulphuric acid or ammonium sulphate sprayed on the brick or incorporated into the mortar may inhibit disintegration by carbon deposition. It is also possible that, in certain instances, traces of impurity in the gas may enhance the catalytic activity of iron or its oxides which may help to explain why a given brick disintegrates faster in one furnace than in another.

Slag–Metal Reaction

Rate questions also arise in considering the reaction between slag and metal and may be as significant as equilibrium considerations. We have already noted that the assumption that slag and metal are substantially at equilibrium is no longer valid. This belief was based largely on the premise that since the temperature in the hearth is very high all reactions must go rapidly. Yet the work of Hatch and Chipman[8]

indicates that it may take many hours to reach equilibrium. The three-phase investigations of Filer and Darken,[9] already mentioned, suggest that when proper consideration is given to the gas phase in the slag–metal reactions, the time to achieve equilibrium may not be so great—but one or two hours may still be required. This illustrates the danger of considering only some of the significant factors, for although it is probably true that the specific reaction velocity of slag–metal reactions is very great at these high temperatures, one must also take into consideration physical factors. From this viewpoint reactions across a liquid–liquid interface can be expected to be relatively slow unless the liquids are very fluid and there is good mixing.

Effect of Other Reactions

Other interesting rate problems are the rate of dissociation of limestone and the rate of decomposition of water vapour which may enter the furnace with the charge or through the tuyere. In these instances, the rate of the reaction determines the position in the furnace at which the reaction that may have significant consequences occurs most rapidly. If the course of these reactions is disturbed it may upset the whole balance of the steady state. The consideration of the blast-furnace as a non-equilibrium steady-state process deserves more attention than it has yet received.

CONCLUSIONS

These few illustrations, which by no means exhaust the subject, serve to stress the significance of equilibrium and reaction rate in blast-furnace problems. Proper attention to them can aid the operator in determining what he may hope to attain in furnace performance and how he may avoid undesirable side reactions. Perhaps, greatest of all, they offer the best promise of achieving complete understanding and control of this process.

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Authors are reminded of the requirements of the Publication Committee for the submission of papers for publication in the *Journal of The Iron and Steel Institute*.

(1) Manuscripts should be typed, in double spacing, on one side of the paper. Duplicated reports, unless printed on non-absorbent paper, cannot be accepted.

Mathematical expressions, Greek, or other symbols should be hand written, with ample allowance between typescript matter.

(2) Diagrams should be drawn in black Indian ink on tracing cloth, Bristol board, or stout drawing paper, and generally should be at least twice the size of the final reproduction, which will usually be at column width (3⅛ in.) or page width (6½ in.). All lettering should be written in pencil, either on the original drawing or preferably on a separate print (if a print is possible) or rough sketch.

(3) Photographs (unmounted) should be printed on glossy bromide paper to give sharp contrast. It is helpful to the Editor if authors indicate on the back of the print the important area of the photograph which is to be reproduced, as this enables the block to be made at the smallest size without unnecessary reduction. All diagrams and photographs should be numbered and should be accompanied by a list of captions attached to the manuscript.

(4) Tabular matter should be kept to a minimum and should not repeat data already shown graphically.

DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

ANNUAL GENERAL MEETING, 1950

THE ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 26th and 27th April, 1950, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. Sir ANDREW MCCANCE, LL.D., D.Sc., F.R.S., the Retiring President, occupied the Chair for the first part of the first session, his place thereafter being taken by Mr. J. R. MENZIES-WILSON, O.B.E., the new President.

The Report of the Meeting was published in the February 1951 issue of the *Journal* (pp. 135–140).

Discussion on the Paper—

CHARACTERISTICS OF SCRAP IN RELATION TO BULK HANDLING*

By E. L. Diamond

Mr. **E. L. Diamond** (British Standards Institution) briefly presented his paper.

Dr. **D. Binnie** (Lancashire Steel Corporation, Ltd.): Alterations in size, design, and lines of open-hearth furnaces have all been made to increase outputs; also, the use of fuel oil, and instrumentation generally, has resulted in speeding up the process, so it is natural that attention should be paid to improvement in the preparation and charging of scrap.

The author has virtually placed the handling of scrap on an engineering basis. The scrap will be segregated, sized into recommended shapes, and charged into the furnace, possibly by a chute. I agree that the author's conclusions on the preparation of scrap suitable for bulk handling can hardly be disputed, but I am concerned rather with the attempt to put the charging of an open-hearth furnace on to an engineering basis.

The open-hearth furnace must be viewed as a metallurgical job. Scrap has to be added when the furnace requires the scrap, not any quicker nor more slowly. The scrap already in the furnace must be heated up and partially melted before any more is added, so that production is not held up by chill. Moreover, the open-hearth furnace itself is very fragile. If too much scrap is added the flame is deflected to the roof; also, the light scrap already in the furnace might be forced up to the roof, pushed by the next load coming in.

It would be a very big departure for the open-hearth department to embark on a method of scrap segregation of this kind. The only way to do so would be to see that the scrap, when it arrived at the works, was sized, bundled, and baled in the way suggested by the author. This would have to be done by the people handling the scrap; the open-hearth department could not do it under present conditions.

Scrap is not so uniform as the author believes. Many casts of steel have to be kept down to low percentages of extraneous metals such as copper, nickel, tin, etc. Men have to be employed inspecting and sorting out such non-ferrous materials, or ferrous materials containing non-ferrous parts. A considerable amount of non-ferrous metal can be collected in this way, and personal inspection of scrap, apart from sizing, must be carried out. This should be another job for the scrap supplier, but it may be asking too much from him.

Another issue which makes the personal inspection of all scrap imperative is the danger of live shells, and explosives generally, finding their way into the furnaces, or at least into the scrap. It is only by keen inspection that this can be avoided, so the day of the complete mechanization of scrap by sizing alone is still far off.

The author suggests that mill scrap should be sheared to useful lengths for charging into the open-hearth furnace. This is already an established process, and bloom crops and billet crops are dealt with in this way.

Certain types of scrap (*i.e.*, pies, ingot ends, skulls) to which the author does not refer, since all steelplants have to contend with them, cannot be conveyed on a mechanical belt to a chute and into the furnace. Therefore if the new method of scrap handling were introduced, the old method would still have to co-exist alongside it.

Mr. **J. H. Flux** (The United Steel Companies, Ltd.): Now that the tests have been reported, it is easy to argue that the materials used in the author's tests were not sufficiently representative. Scrap, as received at most works, is so varied that the author's selection of test materials might well have been wider. His suggestion that surface roughness is only a secondary effect and may be safely neglected really requires experimental confirmation by the use of partly corroded pieces.

* *Journal of The Iron and Steel Institute*, 1950, vol. 164, April, pp. 452–462.

It is appreciated that, for the regular shapes used in the tests, the effect of surface roughness is probably less pronounced than with actual scrap, but any results of tests of the kind suggested would indicate the direction and degree of deviation between practice and assumed theory.

For Table I (p. 454) only two sizes of container, which were relatively similar, were used. We have the impression that, having obtained fairly consistent results, the author was tempted to jump to conclusions. He argues that the variations in dimensions of charging boxes are somewhat limited and that his selection was justified ; but it would have been more satisfactory if, say, four sizes of container had been used instead of two.

The author has placed some emphasis on the aperture test, but the interpretation of his results appears to need a little further explanation. In equation (1) on p. 456, he has assumed that A (the width of the aperture) is independent of the width of the container and the height of the heap above the aperture. Whilst the first part of this assumption is correct, it is not quite so obvious why A should be independent of the height. The expression which he obtains gives the average shear stress and not the maximum, but as the expression for maximum shear stress may not be a linear one, H might not be cancelled out. Also, with regard to the interpretation of the tests as shown in the graphs, we are more interested when H is of the order of a few inches, and it seems desirable to analyse the lower portion of the curve, and not to draw conclusions from the upper portion.

Possibly the greatest value of the work discussed is in obtaining data for the preparation of works scrap, which is generally of more or less regular form ; but as the use of only one or two types of scrap is not likely in the majority of cold-melting shops, where scrap charging is the acute problem, it would be desirable to extend this series of experiments to include a rather wider variety of specimens and shapes than those shown in Fig. 5. So far as the tests with bent pieces are concerned, it would be interesting to learn whether by increasing the length/diameter ratio the aperture will remain the same as for straight pieces of the same length/diameter ratio.

The author does not actually forecast the future ; he gives the impression that he has already formulated the solution in his own mind ; namely, increased scrap preparation followed by orthodox methods of charging, ruling out improvements resulting from the development of novel equipment. It would be interesting to know whether his ideas have been interpreted correctly.

Mr. **R. W. Evans** (Steel Company of Wales, Ltd.) : When one looks at a wagon-load of scrap or a heap on the ground, one wonders how such an assortment can ever be made amenable to mathematical treatment. All the more credit should therefore be given to the author, for making the effort to reduce the subject to something which will be useful in further attempts at preparation.

The great difficulty of this problem makes it all the more necessary that initially we should recognize what are the most important properties of the scrap with which we are dealing. The author of the paper considers this question of bulk handling to be more important than the attainment of maximum bulk density in the charging box. With that I must disagree. We all have to put scrap to stock, and the great difficulty as I see it is that, whilst it is relatively easy to get it out of stock, it is not quite so easy, with particular types of scrap, to get enough weight into the charging box to avoid delay in the charging and melting operation.

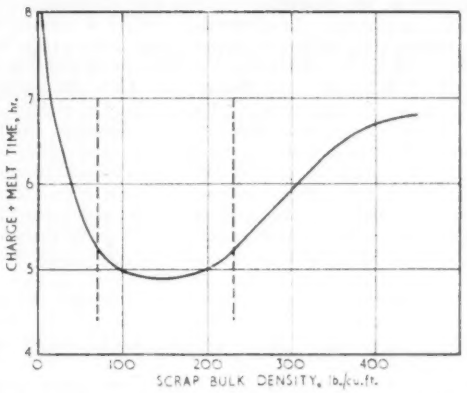

Fig. A—Relation between bulk density of scrap and its melting time in the furnace

It might be argued that the most important point in considering scrap shape and size should be the form in which it will melt fastest in the open-hearth furnace, and that, having decided this, we should devote all our efforts to trying to attain that shape and bulk density. For instance, if a charging box of 40 cu. ft. capacity could be filled with solid steel, it would hold approximately 9 tons. Considering this charging box in association with a 200-ton furnace working on 50% of hot metal, the whole of the scrap charge could be put into the furnace with 12 boxes, and, with the present speed of charging, in about 6 min. That, in my view, would not lead to fast melting ; the extreme chilling effect, mentioned by Dr. Binnie, would necessitate a fairly long recovery period for the furnace and the whole system. On the other hand, when dealing with extremely light scrap the melting time is prolonged, owing to the sheer inability to keep up with the furnace requirements of scrap.

If, therefore, melting time in the furnace is plotted against the bulk density of the scrap, a simple curve very approximately of the type shown in Fig. A is obtained. We admit that both very heavy and very light scrap are not good, and so we try to keep on the portion of the curve between the dotted lines. The lowest point will vary according to the furnace and the layout of the shop, etc., and each shop must work out its own scheme.

One type of scrap which provides a real headache is ship-breaking scrap, which can have all sorts of shapes. In particular, it is extremely difficult to obtain adequate box weights with **T**-shaped sections, **L**-shaped sections, and their variations. A **T**-section stood up vertically wastes considerable volume ; placed upside down it probably jams half way down the box ; if placed on its side possibly part of the volume above can be filled up. But in all cases there is waste of volume. Has the author any suggestions on how to deal with these very difficult shapes ?

I think that, in general, steelmakers might take exception to some of the author's conclusions. From my experience, I would say that a series of bent and twisted objects gives considerably more trouble than straight ones, and I consider that the most important question is how to increase the bulk density. I have always in mind that we have to put up with the present methods of charging open-hearth furnaces. If it were practicable to use, for instance, the chute shown on p. 462, then the entanglement capacity of scrap would, I agree, be the most important factor to consider.

Mr. **P. G. W. Hawksley** (British Coal Utilization Research Association, Leatherhead) : First I should like to confirm that scaling up from model tests really does work. We have carried out various model tests on the design of bunkers, and found that they do work in practice on the large scale. That is for the static case, but for the dynamic case of, for example, feeding mechanisms, it is possible to scale up the rates also.

If, at any stage of handling, the scrap passes through a constriction, for example, through a chute or past a gate, I am not certain that the aperture test alone is a sufficient guide to the rate at which scrap can be handled, because the rate at which a mass of material can pass through any sort of constriction is very dependent on the size of that constriction, and varies approximately as the $\frac{5}{2}$ power of the size, for equi-dimensional pieces. There is likely to be much more trouble with pieces of large length/diameter ratio.

The author mentions that these tests gave rather scattered results, and I think it would have been useful if he had included the maximum as well as the average values in the aperture test. It is not altogether helpful to know the length/diameter ratio that will give trouble on the average ; one wants to know the value that will always be satisfactory.

Mr. **W. B. Baxter** (Vice-President, Appleby-Frodingham Steel Co.) : One of the most primitive and archaic features of a modern melting shop is the method of charging scrap, and if the author had done nothing else but draw attention once again to this method of charging cold metal into steelmaking furnaces, he would deserve the gratitude of the Institute. Why we are still struggling with this problem, trying to make all sorts of scrap go into a steelmaking furnace instead of preparing the scrap in a proper manner and putting it into the furnace molten, is difficult to understand.

AUTHOR'S REPLY

Dr. **E. L. Diamond** wrote in reply : Dr. Binnie is quite right in saying that I have approached the problem of scrap handling from an engineering point of view. When the necessary chemical segregation has been carried out it remains an engineering problem of great magnitude, as is proved by the fact that even in plants with comparatively slow melting furnaces, delays in supplying scrap to the chargers are often the limiting factor in output. All Dr. Binnie's arguments support the case for continuous mechanical handling of scrap. The present tendency with modern stage railway systems and fixed chargers is to charge large quantities at a high rate for short periods, with long intervening periods for melting down. The main purpose of a continuous handling system is to eliminate the necessity for long intervals while scrap bogies are shunted about, and thus to provide a completely flexible supply system which can charge for any period required, and at any rate required, according to the conditions in the furnace—in fact, to keep always to the optimum rate illustrated in Fig. A. Furthermore, the necessity for carefully looking over scrap, either by the merchant or on arrival at the steelplant, means that segregation on a size and shape basis can be carried out at the same time and would not be a costly additional process.

It is stated in the paper that the more intractable pieces of scrap would have to be dealt with separately, and this would apply to skulls, etc. To be able to handle, by continuous means, the greater part of the scrap supplied, would be sufficient to eliminate scrap charging from the factors limiting output.

Mr. Flux's suggestion that the materials used were not sufficiently representative is a very understandable criticism. But could he suggest a list of more representative shapes ? If he considered the problem as it first presented itself to the author, he would see that unless he formed a clear conception of a logical series of shapes, he might carry out thousands of experiments without being able to draw any definite conclusions. The choice of the ' shape ratio ' was not purely an intuitive guess, but was the result of many exploratory experiments in the early stages of the work. I had planned to construct a fairly large-scale model of a section of a plate-type conveyor from which scrap could be dropped into a pan-shaped receptacle. That, I suggest, would be the stage at which to consider subsidiary problems that might present themselves in the application of the theory to practice. The purpose of this laboratory work was to provide a basic theory or framework on which to build, and in this it was more successful than I had expected at the outset.

I agree with Mr. Flux that, in practice, depths of scrap within the lower curved part of the graphs will be encountered, but any theory based on results at such depths would have been guess-work, whereas the relationship between the straight parts of the graphs and the curved parts is clear enough for practical purposes : moreover, the straight part represents the worst conditions. The conclusion that the aperture is independent of the depth was a matter of experimental observation, and was not an assumption. There is therefore no reason to suppose that the average shear stress is variable.

Mr. Flux's and Mr. Evans's remarks on my view of the future solution of the problem more or less cancel out each other. Figure 1 in the paper indicates that I envisage the development of novel equipment, but I am glad to know I have not given any impression that this work cannot be related to present-day problems and methods. At the same time, I would point out to Mr. Evans that the picture he suggests of a scrap trimmer solemnly debating with himself at precisely what angle he should deposit a piece of **L**-section in a pan so as to get the best bulk density, presents as vividly as possible the fundamental weakness of the pan system, and the argument in favour of developing something better. This difficulty could only be solved in each case by an elaborate calculation taking into account a number of dimensions relating to the pan and the furnace, and to the particular piece of scrap ; little improvement can be looked for along these lines so far as everyday operation is concerned.

The conclusion regarding twisted pieces of scrap was not intended to refer, as Mr. Evans appeared to assume, to unprepared scrap. It must be considered together with the other conclusions of the paper, and should be applied only to scrap prepared or segregated for bulk handling in accordance with the proposed rules.

I am grateful to Mr. Hawksley for his confirmation of the validity of small-scale experiments in this field. A more detailed account of the experimental results has been reported by B.I.S.R.A., giving the range of values for the aperture tests. I do not envisage, however, attempting to pass scrap in bulk through a constriction in the line of flow ; that would enormously increase the difficulties.

I appreciate Mr. Baxter's comments, but whether scrap should be pre-melted is a question outside the terms of reference of the investigation ; however, even if that is the ultimate solution I hope the paper may still be a useful guide to those who will have to design the plant for feeding the pre-melting furnace. But whatever the future may hold, the present research needs to be followed up by practical experiments, on a small scale at first, on the lines I have suggested earlier in my reply.

Joint Discussion on the Papers—

THE OVERHEATING AND BURNING OF STEEL. Part III—THE INFLUENCE OF EXCESSIVE REHEATING TEMPERATURES ON THE MECHANICAL PROPERTIES AND THE STRUCTURE OF ALLOY STEELS*

By A. Preece, J. Nutting, and A. Hartley

THE DETECTION OF OVERHEATING AND BURNING IN STEEL BY MICROSCOPICAL METHODS†

By A. Preece and J. Nutting

GRAIN-BOUNDARY PHENOMENA IN SEVERELY HEATED STEEL‡

By T. Ko and D. Hanson

A NOTE ON THE OVERHEATING OF STEEL§

By E. C. Rollason and D. F. T. Roberts

Professor **A. Preece** (King's College, University of Durham) presented the first two papers, Dr. **T. Ko** (University of Birmingham) presented the third, and Dr. **E. C. Rollason** (Murex Welding Processes, Ltd.) presented the fourth.

Mr. **J. Woolman** (The Brown-Firth Research Laboratories) : My first reaction on reading the papers was to note the increasing evidence which is being brought forward to show the importance of sulphur in this phenomenon of overheating. It is very gratifying to see the confirmation of the suggestion which Mr. Kirkby and I put forward in our paper in 1946,* and on which I enlarged in the discussion on that paper,† that overheating was caused by precipitation, on cooling, of sulphides at the grain boundaries. This deduction was made by a process of elimination. We also indicated that the phenomenon might be expected to be influenced by the manganese content of the steel. The papers by Ko and Hanson and by Rollason and Roberts bring more concrete evidence in support of this theory. Preece and his co-workers, however, still show considerable caution, and are reluctant to support the precipitation theory of overheating. I do not want to anticipate anything that Dr. Ko is going to say later, but I should like to answer some of the objections put forward by Professor Preece.

He states that sulphur solubility does not increase appreciably until burning is approached. However, only a very slight increase in solubility at and above the overheating temperature is necessary to explain the phenomenon, especially in view of the extreme fineness of the boundary precipitate. Again, he states that if the faceted fracture were due to the presence of a film of some precipitate, serious reduction in strength would be expected. This, however, would depend on the thickness and continuity of the film, and unless the film were very marked it is not to be expected that the ordinary mechanical properties would be affected seriously, although the impact properties would be the first to suffer. That is what Preece and his co-workers generally found.

They also state that a precipitate at the grain boundary should not influence the tempering properties of the grain boundary. This, however, is not a valid argument, since the effect of tempering is to toughen the grain and thereby to ensure that the fracture takes place at the more brittle boundary, rather than through the grain. With a brittle grain, as with as-quenched specimens, the fracture tends to go across the grain as readily as round it, and the facets are not as easily obtained. The weakened structure in Fig. 16 is said to have an appreciable thickness and to be continuous with the rest of the material. We have pointed out previously, however, that the wide etching band shown in this microphotograph is not the precipitate, but is probably the zone of metal from which the element forming the precipitate has diffused. I think Dr. Rollason put that point forward in presenting his paper. It is this modified composition near the precipitate which is responsible for the etching effects described in the paper by Preece and Nutting. I have not found any definite evidence that the change-over in the nature of the boundary markings, whether black to white or white to black according to the etchant used, is coincident with the initiation of burning. It may be so, as Dr. Ko has indicated, but whilst it is true that certain samples examined definitely show burning, as judged by the presence of eutectic structures, there are many samples in which there are no such signs of incipient melting. In my view, the differences in structure are purely etching effects, and depend on the intensity of the precipitation and on the change of composition near the precipitate. Similar types of etching effect are obtained in austenite steels, depending on the severity of the precipitation which has taken place with minimum overheating temperature.

Ko and Hanson are to be congratulated on their contribution, and in particular on their excellent photomicrographs, especially those in which, as in Figs. 12*a* and *b*, the eutectic formation of the precipitates is illustrated. Perhaps these authors can say whether the presence of such evidence of fusion by the precipitate is coincident with the change-over in the etched structures.

I was also interested in their results on the low-sulphur steels made from pure materials. Are faceted fractures,

* J. Woolman and H. W. Kirkby, *Journal of The Iron and Steel Institute*, 1946, No. I, pp. 265P–279P.
† *Ibid.*, pp. 282P–283P.

* *Journal of The Iron and Steel Institute*, 1950, vol. 164, Jan., pp. 37–45.
† *Ibid.*, pp. 46–50.
‡ *Ibid.*, pp. 51–62.
§ *Ibid.*, Apr., pp. 422–424.

in their opinion, obtained on such low-sulphur steels and do they have a low or high overheating temperature, based on the production of faceted fractures ? If they have, then one of the arguments against the sulphide precipitation theory is answered. This argument is that if the theory were correct one would expect there to be a sulphur content below which an increase of overheating temperature would result. So far, there has been no evidence of such a low sulphur content associated with minimum overheating temperature.

Rollason and Roberts put forward an interesting theory, particularly with regard to the influence of manganese. This theory fits in well with our conception of overheating, but it is far from being substantiated by the experimental evidence put forward. Thus, it is doubtful whether the lines drawn in their Fig. 3 are closer to lines of constant manganese sulphide or to lines of constant manganese. In Fig. A, I have superimposed on their Fig. 3 two lines, corresponding to constant manganese contents of 0·4% and 0·8% respectively. The former lies very close to, and is almost parallel over the whole of the length of, the lines corresponding to steels having overheating temperatures of 1300° C. The 0·8% Mn line crosses the line corresponding to steels with overheating temperatures of 1400° C., but there are relatively few points to draw in accurately on the latter, especially for Mn/S ratios exceeding 30. If the overheating temperature lines become parallel to the horizontal axis, as required by the theory they put forward, it is difficult to visualize how steels with exceedingly low sulphur contents could have high overheating temperatures. In other words, a steel with no sulphur content should, according to the trend of the curves, have an exceedingly low overheating temperature. If, however, the lines for constant overheating temperature continue their trend downwards and become asymptotic to the Mn/S ratio axis, then steels with very low sulphur content and moderate manganese content would have very high Mn/S ratios, which might take the steel into the regions of the higher overheating temperature portions of the graph.

I took three steels of low manganese/sulphur ratio to try to check the more sensitive region on the right. The steels were : a plain carbon steel, with a Mn/S ratio of 13/1 and an overheating temperature of 1350° C. ; a 3½% nickel–chromium steel, with a Mn/S ratio of 11·7/1 and an overheating temperature of 1300° C. ; and a nickel–chromium–molybdenum steel, with a Mn/S ratio of 11·8/1 and an overheating temperature of 1350° C. According to Fig. 3 of the paper, the overheating temperatures should be about 1300° C., 1275° C., and 1300° C., respectively. These results may not be considered to check the theory very well, but it must be remembered that there are factors other than manganese and sulphur which affect the overheating temperature. Aluminium has an important influence, and other elements may be of some importance. If all these factors are considered it might be possible to obtain more acceptable evidence to support the theory or to suggest some slight modification of it.

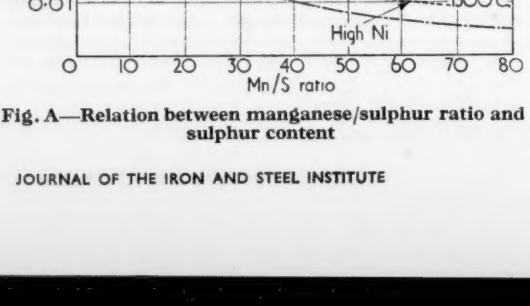

Fig. A—Relation between manganese/sulphur ratio and sulphur content

Dr. **J. H. Whiteley** (Saltburn-by-the-Sea). On reading the excellent paper by Preece and his collaborators, I had the impression that the authors suspected sulphur to be the main cause of overheating, although they were unable to see how some of their results could thus be explained. I think the other two papers should help them considerably in that direction. I have only one criticism to make. In Fig. 18*b* the authors have drawn a straight-line curve through only two points. The shape of a curve cannot, in general, be so determined, and I feel sure that if two or three intermediate points were obtained the curve would be found to be of the same type as the other four in the graph.

Ko and Hanson described a round inclusion which was not attacked by etching reagents, did not heat-tint below 450° C., and was not stained by boiling alkaline sodium picrate. For these reasons the authors considered the inclusion to be iron phosphide. I am not satisfied with this conclusion, because a well-known test for iron phosphide is that, when heat-tinted, it becomes blue considerably below 450° C., while the colour of the carbide has not advanced beyond red. Some years ago I described a very similar particle which appeared in a series of bath samples.* It was not stained by boiling alkaline sodium picrate, but was well darkened when left for two hours in that solution at room temperature. As it remained red in colour when heat-tinted up to 400° C., I inferred that the inclusion was some form of carbide.

With regard to the solubility of MnS in steel at high temperatures, I think that, before solution occurs, part of the MnS at the margins of the inclusions is probably first changed to FeS, and that it is the latter compound which dissolves, for we know that FeS is soluble to some extent. In slow cooling, the dissolved sulphide is either deposited on existing sulphide inclusions or is precipitated as very fine particles both within the grains and at the boundaries. However, I do not think that in the latter position these particles can be more than a contributory factor in overheating. In the first place, steels containing only 0·01% of sulphur can be severely overheated even below 1300° C., and in such cases the number of sulphide particles precipitated at the grain boundaries can scarcely be sufficient to give rise to the trouble, especially as all of the MnS would not be dissolved at that comparatively low temperature. Secondly, very pure iron which has been refined by melting for a long time in hydrogen and then evacuated can be extremely brittle with an intercrystalline fracture, even when the sulphur content is below 0·004%. Since other impurities have been almost completely eliminated, this brittleness appears to be caused by the presence in solution of sulphide at the grain boundaries, and I consider that a similar effect occurs in overheating. Sulphur, and possibly oxygen in solution at the grain boundaries, alters the surface tension in a way such that, when the grains are toughened by quenching and tempering, fracture occurs at the boundaries rather than through the grains.

I can find no evidence in the paper to support the authors' conclusion that the intensity of sulphide precipitation at the austenite grain interface will depend

* J. H. Whiteley, *The Iron and Steel Institute*, 1937, *Special Report No.* 16, pp. 40–42.

indirectly on the de-oxidation, casting, soaking, and rolling practices. The improvement in physical properties after normalizing may be largely the result of a smaller grain size.

Dr. **J. Nutting** (University of Cambridge) : On p. 423 of the paper by Rollason and Roberts, the line AB in Fig. 1 is a very arbitrary one, particularly since the oxygen contents of the steels are not considered. The line is drawn to pass through the co-ordinates for steel 31, but this steel has the highest oxygen content of the series and so would be expected to have a fairly high inclusion content. It is not safe to assume, therefore, that all the sulphur in steel 31 is present as massive sulphide inclusions.

In regard to the theory of Rollason and Roberts, that it is the precipitation of manganese sulphide which is responsible for overheating, Ko and Hanson have shown that the inclusions present at the austenite grain boundaries are both manganese sulphide and iron sulphide. Thus, if inclusions alone cause the intercrystalline weakness associated with overheating, it seems strange that it is only manganese sulphides which are effective.

Two theories have been advanced to account for the phenomena associated with overheating. Ko and Hanson believe in the precipitation of sulphides at austenite grain boundaries : Preece, *et al.*, believe in a change in composition at the grain boundaries brought about by a diffusion process. We should try to reconcile these two viewpoints, as I do not believe that they are mutually exclusive.

Both precipitation and diffusion can account for some of the phenomena recorded in the present papers, but the precipitation theory alone cannot explain the action of the ammonium nitrate etchant. Ko and Hanson state that the electrochemical behaviour of the matrix in the neighbourhood of the inclusions must be affected by their presence, thus giving rise to the etching effects observed with other specific chemical reagents, *e.g.*, ammonium nitrate and molten zinc chloride. If this is so, then an ammonium nitrate etch should give a white band round any sulphide inclusion found in overheated steel, whether it is a sulphide inclusion, formed by precipitation during overheating, or a massive sulphide inclusion formed when the ingot solidified ; but this band has not been observed.

Steels cooled at 3° C./min. from a high temperature do not show white boundaries with ammonium nitrate ; yet, according to Ko and Hanson, sulphide inclusions are still present at the grain boundaries, and white boundaries should be obtained. It is evident, therefore, that the ammonium nitrate shows an effect which cannot be accounted for simply by precipitation.

The evidence obtained by Preece, on the action of the ammonium nitrate etchant, indicates that the region of the pre-existing boundary becomes passive more readily than the bulk of the grain. This condition is not likely to arise simply by the presence of a precipitate ; some other changes are required. It may be that, during the formation of manganese sulphide precipitates at the grain boundaries, the austenite in the neighbourhood of these precipitates is depleted with respect to manganese. This deficiency may be retained after heat-treatment, giving a purer ferrite, which results in the etching effects observed with ammonium nitrate.

As sulphur goes into solution in the austenite, manganese enrichment should occur round the massive sulphide inclusions formed during solidification of the ingot, and therefore no white boundaries should be formed round these inclusions. Rapid cooling from the high temperature prevents the formation of sulphide precipitates and the removal of manganese from the austenite ; as a result, no white boundaries are found with the ammonium nitrate etchant and the steel is not overheated. Slow cooling from the high temperature allows the manganese deficiency, set up when the sulphides are formed, to be removed by diffusion. Therefore a slowly cooled steel, when etched with ammonium nitrate, shows no white boundaries, and, because the precipitates are in a globular rather than an elongated form, they do not have the same weakening effect. The absence of manganese will also lower the resistance to impact of the ferrite, and this may be a factor contributing to the intergranular weakness found in overheated steel.

Dr. **T. Ko** (University of Birmingham) : Dr. Rollason's analysis has provided further indirect evidence that the precipitation of sulphide is the cause of overheating. With regard to the results of Preece and his co-workers, we agree in almost all the important observations which can be made on polished sections ; it is only in their interpretation we may disagree here and there.

Professor Preece has rightly drawn our attention to a few facts which should be accounted for in any theory of overheating. These observations, however, either can be explained or are expected on the basis of precipitation theory, and Mr. Woolman has anticipated my answer to these objections.

The alternative theory (that overheating is caused by segregation of alloying elements in solid solution in the grain-boundary regions on heating to high temperatures) has been advanced by Colombier* in his discussion of Professor Preece's earlier paper in 1946, chiefly owing to the lack of evidence then that any precipitates are present at the grain boundaries in a polished section.

It is very probable that segregation of some elements exists at the grain boundaries. Bragg† has suggested that solute atoms can more easily find suitable atomic sites of convenient size in the irregular boundary region than in the lattice itself. Gibbs has shown that the excess concentration E of the solute per unit area of surface is proportional to the activity or, for dilute solutions, concentration C of the solute, and to $\frac{d\gamma}{dC}$, where γ is the surface tension, and that it is inversely proportional to the absolute temperature.

Steel does not need long soaking for overheating, hence the effect of rate of diffusion cannot be used to explain why the severity of overheating increases with increasing temperature. To account for this observation, therefore, we must, on the basis of the segregation theory, assume that the segregation or the excess concentration E at the surface also increases with increasing temperature. As it is very unlikely that the rate of change, $\frac{d\gamma}{dC}$, would increase with increasing temperature, the increase in excess concentration with increasing temperature is possible only when the concentration C increases with increasing temperature. For elements such as phosphorus and silicon, which are already in solid solution at low temperatures, this is not possible. Indeed, Professor Preece and his co-workers have found in their statistical analysis that phosphorus and silicon have no significance in overheating, and Colombier's finding that these two elements affected overheating must be a secondary effect. Only those elements which are saturated at low temperatures, such as sulphur, can act in the above manner when their solubility in austenite increases with increasing temperature. The precipitation of

* L. Colombier, *Journal of The Iron and Steel Institute*, 1946, No. I, pp. 298P–301P.

† W. L. Bragg, *Proceedings of the Physical Society*, 1940, vol. 52, pp. 105–109.

these inclusions will then be expected when the austenite becomes supersaturated with sulphur on cooling.

The existence, at the grain boundaries, of such a segregation of sulphide which precipitates during cooling can be used to account for the anomalous grain-growth phenomena observed by Preece and his co-workers (p. 42). Grain growth takes place when such growth reduces the free energy of the system. If the grain boundaries are saturated with substitutional solute atoms, then the activation energy for growth will be increased, because of the lowering of the free energy of the grain boundaries ; the rate of growth is thus reduced and no subsequent grain growth is observed. Long soaking at high temperatures, therefore, will not increase the austenitic grain size.

If the steel is subjected to cyclic heating and cooling, then the precipitation of large inclusions, which do not hinder growth, at the grain interface during slow cooling will partly remove this segregation and will facilitate the grain growth during heating, the growth being a more rapid process than the solution of inclusions ; consequently, abnormally large grains may be produced by temperature fluctuation.

Preece and his co-workers also found that when steels were heated above a certain temperature, A' in Fig. 19*b* (p. 42), which was below their overheating temperature, ferrite was precipitated along the previous austenitic grain boundaries on subsequent isothermal treatment, after oil-quenching and tempering had been interposed between the two treatments. I suggest that, although these temperatures A' are not directly related to the overheating temperature, the formation of ferrite during isothermal transformation was caused by the persistent disturbance introduced by the fine inclusions precipitated at the austenite grain interface during cooling after the initial heating ; this precipitation begins at a temperature about 100° C. below the overheating temperature determined by etching.

AUTHORS' REPLIES

Professor **A. Preece** said in reply : There will be general agreement that overheating involves a change in composition of the periphery of the austenite grain boundary, but I do not believe the evidence supports the conclusion that it is a precipitation of a sulphide at the grain boundary which is responsible for the development of the overheated condition. If this were the case, high sulphur steels (since they would have at least as much, if not more, sulphide precipitate at the austenite grain boundary as the low sulphur steels) would be expected to be highly susceptible to overheating ; yet the opposite is true : high sulphur steels have little or no susceptibility. Alternatively, since all commercial steels contain more sulphur than they are capable of dissolving in the solid state, the overheating properties of all steels should be similar or directly governed by the manganese content ; but this again is not found to be so.

Mr. Woolman suggests that the observed wide etching band, shown in Figure B, is due to the presence of a precipitate. I could agree with him if the band had been attacked in preference to the rest of the grain, but the converse is the case : the etchant has attacked the matrix leaving the network unattacked. Thus the thickness of the band is real, and delineates what was the altered boundary of the austenite grain. It is unlikely that the network, shown in Figure B, was caused by the diffusion of manganese to form the sulphide precipitate, since the width of the bands forming the network would require a diffusion rate for manganese well above that associated with substitutional elements.

Hanson and Ko have shown, by their excellent experimental work, that sulphide precipitation occurs at the austenite grain boundaries as the steel cools through the overheating range. But this has never been questioned ; the problem of demonstrating that it is this sulphide precipitate which is responsible for the overheated condition still remains. A high-sulphur steel would show this precipitate, but its overheating tendency would, nevertheless, be very slight.

It is for reasons such as these that the sulphide precipitation theory cannot be accepted with any degree of finality.

Dr. **T. Ko** wrote in reply : In regard to Mr. Woolman's question whether there is a definite relation between the network revealed by etching and the formation of a eutectic, we have found that the appearance of a light-etching network with nital etch in a quenched and tempered specimen is always associated with the presence of eutectic formation of sulphide on the grain interface. While I agree with Mr. Woolman that the network in Fig. 16 of Professor Preece's paper is the result of etching effects, we believe that the reversal of etching behaviour (white to black network with Professor Preece and Dr. Nutting's ammonium nitrate etchant, and less attacked austenite grain-boundary region with nitro-sulphuric acid) is caused by the presence of phosphorus in these regions, because a liquid, which gives rise to the eutectic colonies on the grain interface after cooling, had been formed in a phosphorus-bearing steel during heating. The reversal is therefore a secondary effect, usually observed if the cooling after incipient melting is not sufficiently slow to allow complete homogenization of phosphorus. In my view, incipient fusion in the early stage can take place without evident formation of voids in the structure ; such voids are not expected until an appreciable amount of liquid has been formed.

We have not studied the overheating temperature as a function of sulphur content in Fe–C–Mn–S alloys. A minimum in overheating temperature with decreasing sulphur is expected since no overheating is observed in sulphur-free alloys, whilst steels with a large number of sulphide inclusions have higher overheating temperature than steels with fewer inclusions ; the composition at which the steel changes from a low overheating temperature to a non-overheating type should correspond to the solubility limit of sulphur in austenite at normal heat-treating temperatures. None of the steels so far investigated by various workers contained less than 0·007% of sulphur.

Dr. Whiteley questioned whether the round inclusions (Fig. 26c) found in burnt steels and in the Fe–C–P alloy were iron phosphide. As mentioned in the paper (p. 57), the inclusions *were attacked* by boiling alkaline sodium picrate and *stained* by *neutral* sodium picrate solution, which does not attack cementite. The behaviour of these inclusions during heat-tinting agreed with the generally accepted observation that iron phosphide normally colours more slowly than cementite.* Also, the time and temperature required to remove them indicated that they were phosphide, not cementite. Furthermore, it is impossible, as Dr. Whiteley has already found,† to explain their presence if they were carbide.

While I accept Dr. Whiteley's view that the concentration of sulphur in solution may be higher at the grain boundaries at the high temperature, it is difficult to see how this can be a major factor in causing overheating,

* Metals Handbook, p. 394, Cleveland, Ohio, U.S.A., 1948 : American Society for Metals. Also T. Berglund, Metallographers' Handbook of Etching. London, 1931, Sir Isaac Pitman and Sons, Ltd.

† J. Whiteley, *The Iron and Steel Institute*, 1937, *Special Report No.* 16, pp. 40–42.

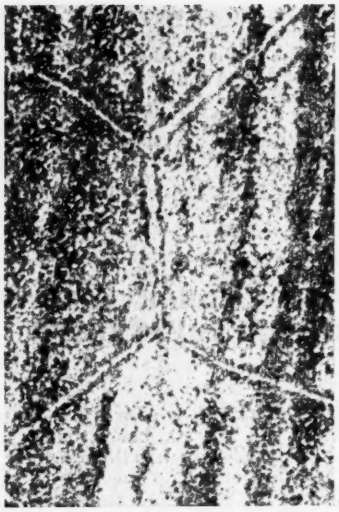

Fig. B—Overheated steel, showing flow lines and white boundaries. Etched with ammonium nitrate × 75

when the overheating temperature is dependent on the cooling rate through the overheating range.* (This difficulty was first pointed out by Woolman and Kirkby.†) The severe overheating below 1300° C. of steels containing only 0·01% of sulphur is not unexpected from a precipitation theory, because the low sulphur or, more exactly, a smaller number of residual sulphide nuclei in the grain after solution will cause heavy precipitation of sulphide inclusions at the grain interface. A high sulphur content does not necessarily increase the sulphur solubility in austenite, but the large number of residual sulphide inclusions in the grain will certainly reduce the amount of sulphide precipitated at the grain interface, thereby decreasing the severity of overheating.

That a small amount of sulphur is sufficient to cause overheating has already been pointed out by Mr. Woolman, who has also remarked on the effects of these inclusions on the strength of the steel. In support of his view, it may be mentioned that intensive precipitation of sulphide in a Widmanstätten pattern similar to that described in our paper (Fig. 25*b*) has also been observed in an air-hardened Ni–Cr–Mo steel (C, 0·27%; Mn, 0·36%; Ni, 3·80%; S, 0·034%) austenitized above 1350° C.‡ The presence of innumerable fine sulphide inclusions on {100} planes caused the specimens, on tensile testing, to fracture along these planes with practically no ductility, but the tensile strength as hardened was only reduced from about 120 to 100 tons/sq. in. before the steel was burnt at higher temperatures.

Dr. Nutting's view on the possible mechanism of the formation of a light-etching network in overheated steel with Preece-Nutting reagent is very interesting. It should be pointed out, however, that the negative segregation can play only a minor part in causing overheating, and that the embrittlement accompanied by the formation of facets in an overheated steel is chiefly due to the presence of sulphide inclusions, because only slow cooling from the overheated temperature or very long annealing at high temperatures can completely remove the previous overheating. Calculations* based on diffusion coefficients of Mn† indicate that segregation of Mn in a scale corresponding to that shown in Fig. 16 of Professor Preece's paper should disappear in a few minutes at 1200° C., whilst much longer annealing is required to remove the tendency to facet formation. For example, Merchant‡ mentioned a satisfactory method for reclaiming overheated steel, by soaking it for eight hours each at 1230°, 1100°, and 960° C. with intermediate coolings before hardening and tempering; and Professor Preece and his colleagues§ have found that an annealing of one hour at 1200° C. was necessary to obtain any improvement in overheated Ni–Cr and Ni–Cr–Mo steels with an overheating temperature of 1300° C. They have also observed that such an annealing was not sufficient to prevent the facet formation in an overheated Cr–Mo steel.

Dr. **E. C. Rollason** wrote in reply: Dr. Nutting's description of the line *A B* (Fig. 1 on p. 423 of our paper) as 'arbitrary' is accepted, but the errors involved are of a minor character. As mentioned in the text, plots of inclusion count *versus* S, O, S + O, and S + 2O were made, which showed that the plot in Fig. 1 was very little different from those taking oxygen into account. As a matter of interest, the curve for S + 1·5O fitted the data best. Dr. Nutting's suggestion that overheating is due to both FeS and MnS would be valid if it had been shown that FeS alone gave the dendritic grain-boundary precipitate associated with the *early stages* of overheating. From the evidence presented, MnS seems to be the agent in this stage; it appears that the FeS forms later, after the overheating phenomenon is established.

Mr. Woolman's suggestion that the lines in Fig. 3 are constant manganese lines had been considered before the presentation of this note. The authors were forced to the conclusion that this was not a better fit. The comment on the presence of other factors is most apposite, for if a separate diagram is plotted for each En specification it is found that, although most of the curves obtained fall on or near the lines in the final diagram, some En specifications—particularly those high in nickel—have a very different distribution. In view of the limited number of observations available on each diagram when made in this way, the authors felt that it would be better to present the admittedly imperfect Fig. 3, which does bring out clearly the general relationship common to all but a very few of the individual diagrams. It has been found that nickel has a marked and unusual effect on the behaviour of sulphides in a totally different connection.‖ With regard to the postulate that the overheating temperature should decrease indefinitely with the decreasing sulphur content, it is believed that this is an impossibility if the theory involving manganese sulphide is true, since a point must be reached at which the amount of MnS present will be insufficient to have any weakening effect. The fact that

* A. Preece, J. Nutting, and A. Hartley, *Journal of The Iron and Steel Institute*, 1950, vol. 164, p. 41, Fig. 17.

† J. Woolman and H. W. Kirkby, *Ibid.*, 1946, No. I, p. 316P.

‡ J. A. Wheeler, V. Kondic, and T. Ko, *Ibid.*, 1951, vol. 167, p. 301.

* J. H. Hollomon and L. D. Jaffe, "Ferrous Metallurgical Design." London, 1947: Chapman and Hall, Ltd.

† C. Wells and R. F. Mehl, *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1941, vol. 145, pp. 329–339. *Metals Technology*, 1941, vol. 8, Technical Publication No. 1281.

‡ H. J. Merchant, *Journal of The Iron and Steel Institute*, 1946, No. I, p. 233P.

§ A. Preece, A. Hartley, S. E. Mayer, and J. Nutting, *Ibid.*, p. 252P.

‖ E. C. Rollason and D. F. T. Roberts, *Welding Research*, 1950, vol. 4, pp. 129r–132r.

such a phenomenon is found is strong support for the theory, for if the overheating temperature decreased indefinitely it could only be construed as indicating the presence of a factor causing overheating that was cancelled out by increasing quantities of MnS until it eventually disappeared. The authors had hoped to show, in Fig. 3 the effect of very low S, but at the time of publication the data were insufficient for presentation as a part of the general theory. Since presentation of the paper, more data have become available, which have fitted the curves in Fig. 3 with reasonable accuracy. It is therefore considered that Fig. 3 gives a useful picture of the overheating data, and from it may be deduced the somewhat over-simplified guide to users that, to avoid overheating, the steel should contain not less than 0·025% of sulphur and have a Mn/S ratio greater than 20.

Discussion on the Paper—

THE EXTENSION OF THE Ar_1 RANGE WITH CARBIDE FORMATION IN MILD STEEL DUE TO HIGH-TEMPERATURE TREATMENT*

By J. H. Whiteley

Dr. **J. H. Whiteley** briefly presented his paper.

Mr. **W. Barr** (Colvilles, Ltd.) : A very puzzling feature of the phenomenon of massive carbide is the irregularity of the distribution, and the author states that it is not in any way caused by segregation. Yet he refers to uneven manganese content. I find it difficult to correlate that statement with Fig. 1*b*, where he shows the light and dark areas. It should be easy to check if the irregularity is caused by the possible heterogeneity of manganese, by checking the manganese content of these light and dark areas.

Has the paper any bearing on certain phenomena which we observed in work on the development of low-alloy high-tensile structural steels ? Many of these steels are based on a manganese content of about 1½%, with perhaps about 0·15–0·2% of molybdenum. To illustrate the effect of temperature, we use a steel containing 0·15% of carbon, 1% of manganese, and 0·25% of molybdenum. Heating to 850° C., a 0·5% proof stress of 22·4 tons/sq. in. is obtained ; at 1050° C. the value is 29 tons/sq. in., and at 1250° C. it is 33·4 tons/sq. in. This effect has been attributed to the known influence of grain size on the rate of nucleation of ferrite in the Ar_1 range. Soaking at these high temperatures decreases the total area of grain boundary at which transformation may easily initiate, but the effects observed in this work were thought to be not solely caused by austenitic grain size, and the author's study of a similar effect in plain carbon steels should assist us in following this clue.

One feature which tends to support this grain-size effect is to be found in the specimens in Table I. In the two as-cast ingots, the author clearly demonstrated the existence of massive cementite in the as-cast condition. I take it that this phenomenon was absent from the three plates included among the specimens, or it would have been observed long ago ; but I should like confirmation of this, because the only difference between the plates and the ingots is that in the plates the grain size would be decreased very considerably by the effect of hot-work. (These plates would be heated in rolling to a temperature of, say, 1300° C. or even 1350° C., and slowly cooled.) This phenomenon must therefore be controlled to a certain extent by the size of the austenitic grains. Perhaps the author will elaborate on these points.

Dr. **T. Ko** (Birmingham University) : I should like, first, to summarize the author's observations. He finds :

(i) The Ar_1 range of mild steels is widely extended by heating the steels to high temperatures (up to 1430° C.) and cooling slowly

(ii) This widening effect increases with increasing manganese content

(iii) The effect increases as the temperature rises from 1200° C. to 1430° C., but is smaller if the specimen is rapidly cooled through this range

(iv) The distribution of austenite is uneven. In some grains, on isothermal transformation, bainite and austenite are observed in the specimens quenched after 2 min. at 250° C., but others are fully martensitic

(v) Massive carbide, sometimes together with pearlite, forms from the austenite below 650° C., on slow cooling.

The explanation of the extension of the Ar_1 range by high-temperature heating is to be found, I think, in the author's observation that the part above the knee of the **S**-curve was moved considerably to the right. In Fig. A is drawn the hypothetical **S**-curve for austenite of eutectoid composition. The thin lines show the **S**-curve for the isothermal transformation of the eutectoid austenite after the ferrite separation ; the thick lines show the **S**-curve during continuous cooling. The Ar_1 range will extend to *A* when the steel has been heated

* *Journal of The Iron and Steel Institute*, 1950, vol. 164, Apr., pp. 399–405.

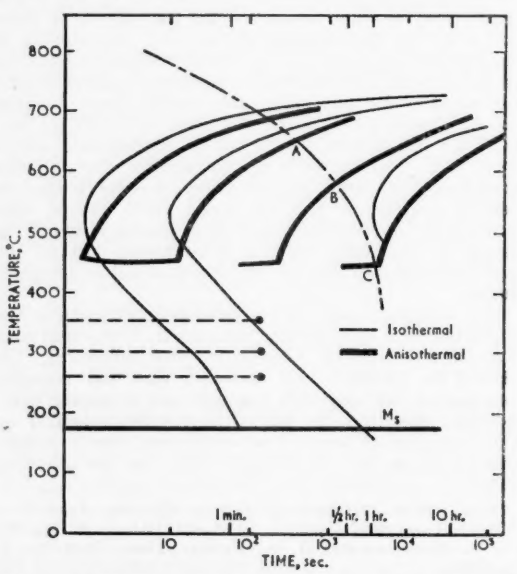

Fig. A—Time/temperature curves for a eutectoid carbon steel

to the normal austenitizing temperature, and to *B* and *C* when the curve has been shifted to its new positions.

The specimens were cooled from high temperatures to 630° C. in about 2–3 hr. If the above explanation is to be plausible, the curve representing the end of the transformation should lie somewhere in this region at 630° C. During our study of overheating and burning in ¼-in. dia. specimens of plain carbon steels containing 0·6% of manganese and 0·5% and 0·8% of carbon (the *S* and *T* steels in our paper*), air-cooled from the austenitic range after being heated to 1420° C., no structure was observed which indicated the presence of austenite after cooling through the Ar_1 range in, say, 10 min. In other words, there was no indication that heating to 1420° C. alone extended the transformation period much beyond 10 min. in those steels. The wide extension of transformation period in the author's specimens can probably be attributed to the heterogeneous structure of the steel at the transformation temperatures below 720° C.

The discrepancy can be explained, qualitatively at least, if it is assumed that the manganese, owing to its higher solubility in austenite than in ferrite, becomes partially segregated in the austenite during the slow cooling. Manganese is known to be very effective in reducing both the induction period and the rate of austenite transformation; the increase in manganese, and of course in carbon, in the austenite during the slow cooling would therefore sufficiently retard the complete transformation. This may also partially account for (ii) on p. 372.

The shifting of the transformation curve by high-temperature heating is probably caused by an increase in the eutectoid austenite grain size after ferrite precipitation. The author has mentioned, on pp. 401 and 405, the change in the grain size. It is tenable, on the basis of a comparison of Figs. 3*a* and 3*b*, to assume that the increase in austenitic grain size will coarsen the Widmanstätten structure, and will therefore coarsen the eutectoid austenite grains after ferrite formation.

The difference in eutectoid austenite grain size would also account for the difference observed between the slowly and rapidly cooled specimens shown in Figs. 10 and 11. The finer structure in Fig. 10 is the result of an increase in the number of ferrite plates in a given volume, after rapid cooling through the high-temperature range. I suggest that this increase is caused by an increase in the number of inclusions, such as sulphide, which nucleate ferrite precipitation from austenite during subsequent cooling. Sulphide is brought into solution when the steel is heated to high temperatures; the number of sulphide inclusions, which may be submicroscopical in size, after cooling will then depend on the rate of cooling through this temperature range. Rapid cooling increases the number of precipitated inclusions, and hence the number of ferrite plates, which in turn reduces the grain size of the residual eutectoid austenite. This speeds up the transformation, with the result that a large extension of the Ar_1 range was not observed.

This probably also explains the effect of the cooling rate through the austenitic range during previous heatings on the austenitic grain size. The author found, in his research on austenitic grain growth,† that an inherently coarse-grained steel containing 0·45% of carbon, after being heated to 1250° C. or higher, showed fine-grained characteristics on reheating to 930° C., and the retarding effect was a function of the cooling rate from the high temperature. Increasing the initial temperature, or the cooling rate from the high temperature, increases the number of fine sulphide inclusions in the steel after cooling, and will therefore increase the retarding effect on the austenitic grain growth of the steel when it is reheated.

If the above theory of sulphide precipitation is accepted, then the unevenness of the persistent presence of austenite can probably be attributed to the minor segregation of sulphide in the steel, in addition to any manganese heterogeneity.

The mechanism by which the massive carbide is precipitated from austenite below 630° C. is less clear. Hultgren* has observed the precipitation of pro-pearlitic carbide below the knee of the **S**-curve in a steel containing 5·05% of Mn and 0·63% of C (which is hypo-eutectoid above the knee), and has suggested that this is caused by a retarding effect of manganese on the nucleation of the ferrite in pearlite. In the present case, the existence of the pro-eutectoid ferrite and the possible formation of pro-pearlitic carbide may have caused the continued deposition of ferrite and carbide from the austenite on the existing nuclei without the formation of pearlite.

The author has observed in his examination of **S**-curves that the bainite part of the curve has not been shifted by the heating to high temperatures. This can be explained on the grounds that bainitic transformation is independent of the austenitic grain size. He also found that specimens isothermally transformed for 2 min. at 350° C. were bainitic, whilst those isothermally treated at lower temperatures contained austenite after quenching. The transformation was slower at lower temperatures, and was therefore not complete in 2 min.; consequently, austenite remained just before final quenching, its amount increasing with decreasing temperature. The M_s or martensitic transformation point of austenite depends on the amount of carbon and other alloying elements in solution, and also on the amount of bainite present. It is known that carbon and manganese lower the M_s point, and that the formation of bainite stabilizes the residual austenite.† If the M_s point of this residual austenite is lowered by the bainite to below room temperature, retained austenite will be found at room temperature. This would account for the observation that, in specimens isothermally transformed at 250° C., grains of wholly martensitic structure and of bainite with retained austenite were both present after quenching to room temperature.

CORRESPONDENCE

Mr. **G. Burns** and Mr. **C. Judge** (Admiralty Materials Laboratory, Poole, Dorset) wrote: It would be interesting to know whether those austenite areas which remain stable to temperatures below the normal Ar_1 range, and which produce massive carbide when they eventually decompose, differ in composition from the major part of the austenite which decomposes within the normal range to produce pearlite. Since the extension of the Ar_1 range increases with increasing manganese content (as is shown in Table II), and considering the known effect of manganese in depressing the Ar_1 range, there is the possibility of some austenite areas being enriched in manganese and so being rendered stable down to low temperatures.

If some such mechanism did, in fact, account for the stability of those austenite areas which give rise to

* T. Ko and D. Hanson, *Journal of The Iron and Steel Institute*, 1950, vol. 164, Jan., pp. 51–62.

† J. H. Whiteley, *Journal of The Iron and Steel Institute*, 1943, No. II. pp. 531P–568P.

* A. Hultgren, *Transactions of the American Society for Metals*, 1947, vol. 39, pp. 915–989.

† A. R. Troiano and A. B. Greninger, Metals Handbook, p. 265, Cleveland, Ohio, 1948: The American Society for Metals. Also A. R. Troiano, *Transactions of the American Society for Metals*, 1949, vol. 41, pp. 1093–1107.

massive carbides on decomposition, it might be expected that the massive carbides would tend to transform on heating at a slightly lower temperature than the pearlite areas, since manganese has a slight effect in depressing the Ac_1 transformation. With this possibility in mind, a few experiments have been made to ascertain whether there is any difference in the temperatures at which the massive carbides and the pearlite disappear on heating.

A piece of mild-steel plate was heated to 1400° C. and cooled at approximately the same rate as that used by Dr. Whiteley to produce massive carbides ; examination of a section cut from the sample showed that massive carbides were present. Other small sections were heated in a lead bath at successively higher temperatures just below and within the Ac_1 range ; after being held at temperature for 15 min., the sections were water-quenched to convert the austenite to martensite, and were then prepared for examination. Three of the specimens treated in this way (those heated at 724° C., 728° C., and 735° C.) are relevant to the point being considered. At 724° C. a part of the pearlite had transformed to austenite, whilst the massive carbides appeared to be unaffected ; at 728° C. most of the pearlite areas had become austenite and the massive carbides were beginning to disappear ; and at 735° C. all the pearlite and massive carbides had become austenite.

These results suggest that the massive carbides go into solution at the same temperature as the carbides in the pearlite, showing only a slight sluggishness such as might be expected from their more massive form ; certainly there is no indication of a tendency to transform at a lower temperature than the pearlite, and the experiment does not support the theory that the austenite areas which produce massive carbides are stabilized during cooling by enrichment in any element which depresses Ac_1. The possibility that these areas may be stabilized by an element which lowers Ar_1 but does not affect Ac_1 is not, of course, excluded.

AUTHOR'S REPLY

Dr. **J. H. Whiteley** wrote in reply : Mr. Barr seems to have misapprehended my remark about an uneven manganese content in the steels ; I merely said that according to Betteridge and Sharpe it was a possibility not to be overlooked. His observations on Mn–Mo steels are very interesting. I made no tests on alloy steels but think it quite likely that molybdenum and other elements, such as nickel and chromium, may lower the heating temperature at which the effect I described begins to be induced. No free carbide was present in the plates I used as samples, nor was there any in a 1-in. plate rolled from a slab which had been purposely heated to about 1300° C. This was not surprising, as the tests indicated that a temperature close to 1350° C. was required before the Ar_1 range was appreciably widened. Also, hot working may reduce that effect. The range stated by Dr. Ko in his item (iii), namely, 1200–1430° C., is too wide, and was not given in the paper. The fact that he and Dr. Hanson could find no marked extension of the transformation period in a 0·80% carbon steel when cooled from 1420° C. confirms my own results on medium carbon steels. The extension of the Ar_1 range produced by a very high temperature treatment seems to be confined to steels with a carbon content below about 0·30%.

I am unable to agree with Dr. Ko that the eutectoid grains increase in size below Ar_3. They must necessarily become smaller as the ferrite separates. As far as I could see, the grain sizes of the specimens slowly and quickly cooled to below 1200° C. were equally large, but their internal structures were, for the most part, apparently not the same as was indicated by the differing patterns given by the pearlite areas within them, which are illustrated in Figs. 10 and 11. I doubt very much whether that difference was due to varying amounts of minute sulphide inclusions, as Dr. Ko thinks, or that they have any influence on subsequent grain growth.

The tests which Burns and Judge have made are certainly informative. If, as suggested by Dr. Ko, the widening of the Ar_1 range is due to the eutectoid grains increasing in manganese below Ar_3, the residual martensite in specimens quenched not far below the lower limit of the normal Ar_1 range should be fairly uniformly distributed ; this was very far from being the case, as I was at pains to emphasize in the paper. Below 900° C. the rate of manganese diffusion is, in all probability, far too slow for any appreciable partition to occur in that way. The fact that I could not reproduce the massive carbide in the ingot specimen, even when it was slowly cooled from 1200° C. (p. 401), also points to the conclusion that an uneven manganese content is not the cause of the effect I have described.

Discussion on the Paper—

THE INFLUENCE OF LOW PERCENTAGES OF CERTAIN ELEMENTS ON THE MICROSTRUCTURE OF PURE IRON–CARBON ALLOYS AND CAST IRONS*

By W. J. Williams

Mr. **W. J. Williams** (British Cast Iron Research Association) presented his paper.

Mr. **M. M. Hallett** (Sheepbridge Stokes Centrifugal Castings Co., Ltd.) : The author has established a *prima facie* case for the importance of oxygen, but the evidence, although very strong, is of course mainly circumstantial. Most of the analyses, for example, are quoted in terms of 'composition sought' or 'percentage added.' It would have added to the weight of evidence if it had been possible to provide the results of actual determinations. Also, the spectrograph might in some cases have been able to give valuable confirmatory evidence, although I appreciate that the specimens were very small.

The method of adding the oxygen seems somewhat crude in relation to the methods of adding the other elements. I was pleased to hear the author say that he would have to carry out a series of melts in which the gas contents were controlled and regulated. This would require melting equipment permitting melts to be made in controlled gas atmospheres. There would then be a chance of obtaining equilibrium conditions, the attainment of which is doubtful when comparatively large lumps of oxide are added to small melts. Under those conditions and with the new experiments, we can expect to arrive at a definite, proved confirmation of the author's

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* *Journal of The Iron and Steel Institute*, 1950, vol. 164, Apr., pp. 407–422.

theories, and the methods would link up with those used by Schneble and Chipman, in the U.S.A.

Reference has been made to the work of Boyles, who suggested in one of his papers that the maximum graphite size was attained at an intermediate graphitizing tendency, and was caused by an optimum combination of rate of nucleation and rate of growth. This theory is not incompatible with the author's oxygen theory.

The structure of the iron/iron-carbide eutectic has been referred to in a number of recent B.C.I.R.A. papers, with particular reference to its degeneration in certain circumstances, and the present paper provides fresh and interesting evidence. One would have expected the attraction of the austenite component of the eutectic to the primary austenite dendrites to be controlled by the free surface energy of the austenite, and it is surprising to find an element such as sulphur exercising such a potent influence. Has the author any further views on the possible mechanism of this ?

On p. 409 is given an analysis of the ash in the graphite. Surely what is meant is that the ash contained 34% of silica, 22% of iron oxide, 14% of alumina, and 28% of lime. Expressing these in terms of the graphite does not seem to have any particular significance.

Mr. **H. Morrogh** (British Cast Iron Research Association) : Cast irons and pig irons of apparently the same chemical composition give structures which may differ considerably, and the literature is liberally interspersed with theories—to many of which the author has referred —attempting to explain these anomalies. Many of these theories are not adequately justified by experiment ; the author's work is a notable experimental contribution to the clarification of our ideas on the subject.

We are, apparently, investigating variations in sulphur and oxygen, and we do not know what those variations are. For example, it is possible that the reported graphitizing effect of sulphur in very small amounts may not be due to the sulphur directly, but to the sulphur influencing the composition with respect to some other element. If this point is not borne in mind, conclusions may be deduced which may be as erroneous as conclusions and theories in the past. We must, therefore, before drawing any definite conclusions, await the further work to which the author has referred.

The observation that high sulphur contents considerably modify the form of the eutectic is interesting, particularly in connection with the ternary alloys based on iron and carbon. It is known that additions of small amounts of phosphorus and of antimony, for instance, have exactly the same effect as sulphur ; they eliminate the characteristic ledeburitic structure in which austenite is the dispersed phase and iron carbide is the continuous phase, and give an iron carbide unbroken and allotriomorphic in outline. With increasing amounts of the third element, the iron carbide becomes idiomorphic and assumes a primary character.

I would suggest that the effect of the three elements is similar, and is perhaps related to the fact that all of them introduce a ternary eutectic into the systems concerned. It is well known that ternary eutectics exist in the iron–carbon–sulphur, iron–carbon–phosphorus, and iron–carbon–antimony systems. Very little is known of the mechanism of solidification of eutectics in binary systems, and still less of the mechanism of solidification, *i.e.*, the solidification sequence, in the binary complexes of ternary systems.

I believe that the findings of the author on the effect of aluminium and similar additions on the form of manganese sulphide may prove of immediate use to the iron-founding industry, and perhaps to others, if the results are applied and used cautiously. It has been known for many years that cast irons and pig irons contain oxygen in some form, and the problem has been to define and know where that oxygen is. (In normal circumstances it is not possible to see the oxygen under the microscope.) The conclusion to be deduced from the author's work is that the oxygen is associated with the sulphide particles, and that, by an appropriate addition of aluminium, the oxygen may be taken out of the sulphide particles and made visible perhaps in the form of some compound, as yet unknown, containing aluminium and oxygen.

Recent work at the B.C.I.R.A., not yet published, has shown that these variations in the form of the sulphide particles, caused by the addition of aluminium, influence the type of sulphur print obtained. If an iron containing the so-called elongated and anchor-shaped inclusions is examined by the sulphur print method, the sulphur appears to be more or less uniformly distributed and with no particular pattern. After treatment with aluminium, or with some aluminium-containing addition such as ferro-silicon, the sulphur print shows the sulphur to be distributed in an extra-dendritic pattern, perhaps indicating that the sulphide particles are formed at a different point in the solidification of the metallic part of the structure. Certain sections of our industry with problems related to this heredity problem could benefit by the systematic study of the sulphur distribution in their materials ; *e.g.*, chilled rolls, ingot moulds, and similar large castings. Sulphur distributions of the two types will be found ; moreover, the microscope will show what the author calls the compact deoxidized type and the oxidized type of particles.

I do not think it is possible, at this stage, to determine the resulting benefit, but many iron-founders suspect there are these variations in oxygen content, and it should now be possible to deduce whether the oxygen in the irons under examination varies or not, without actually determining the oxygen content.

The production of spherulitic nodular structures is extremely important. A successful process is now being developed in the iron-founding industry whereby materials are being produced which may possibly be competitive with cast steels and malleable cast irons. (The characteristic of these irons is that their graphite is in the form of spherulites.) The process depends, among other things, on the reduction of sulphur to a very low level, and on the solution of an element such as magnesium, cerium, or calcium. Rapidly cooled low-sulphur cast irons, even though not containing magnesium, calcium, or cerium, also give graphite in the spherulitic pattern. Published theories of the mechanism of formation of these graphite spherulites tend to consider only one aspect of the problem, and ignore the rest ; in this connection the points raised by the author are of great importance. There must be some parallel between the effect of sulphur itself and the effect of magnesium, cerium, and calcium. Spherulitic structures have been known for many years, but there is no precise information on what causes the crystal habit of a given phase to assume a spherulitic form.

Mr. **N. H. Bacon** (Messrs. Steel, Peech and Tozer) : The Ingot Mould Sub-Committee have been unable to account for the striking difference in the lives of moulds, of the same pattern but made at different foundries, used in one melting shop. This difference has occurred in many works where careful records have been kept. We have made tests of many phases of cupola operation without success, but recently we have found an effect which seems to link up with what the author has said.

One foundry *A* makes moulds which give a life of 150, and another foundry *B* supplies moulds of the same pattern which, used under the same conditions,

give a life of 100. The chemical composition of the moulds is approximately the same. Sulphur prints of the **D**-shaped test pieces cast on the sides of moulds showed a consistent variation between the two makes, *A* being markedly more segregated. This appeared to show that the suphides separated out more readily in the *A* metal.

Next, samples were taken from the extreme top of six moulds (three each of *A* and *B*). In both makes there was intense sulphur segregation in the top ½ in., approximately. In the *A* moulds the ladle samples averaged 0·068% of sulphur (segregated area : 0·222% ; normal area : 0·032%), and in the *B* moulds the ladle samples averaged 0·077% of sulphur (segregated area : 0·388% ; normal area : 0·065%). The degree of sulphur separation was therefore about 54% in the *A* metal and only about 16% in the *B* metal.

Another striking feature was that in the *A* metal the more-or-less homogeneous part had a very even texture, whereas the sulphur print of the *B* metal showed a marked dendritic structure, such as Mr. Morrogh has mentioned. The author's work may link up with this, because whatever causes this difference in the behaviour of the sulphur in the metal may be at the root of the difference in the life.

Our greatest problem is that, having made moulds, we do not know until months afterwards (when the mould life is known) to what extent the cupola metal was satisfactory.

Professor **F. C. Thompson** (Manchester University) : I doubt whether it is strictly true to talk about sulphide inclusions in cast iron and in steel. If these inclusions are examined with sufficient care, it is nearly always possible to show that they are at least duplex. In this respect the work of Benedicks and Löfquist* is worth studying. I believe that the so-called sulphide inclusions are almost invariably sulphide, oxide, and possibly silicate complexes, and that the way in which the different constituents of those complexes exist may have a profound effect on graphitization.

Arnold and Bolsover,† when studying the iron–manganese–sulphur eutectic, showed a very marked effect on the coagulation resulting from the addition of aluminium. This is a direct line of approach to the type of problem with which the author is dealing, and I think that paper is still worth studying.

CORRESPONDENCE

Dr. **R. V. Riley** (The Staveley Iron and Chemical Co., Ltd.) wrote : Although a number of assumptions have been made, Mr. Williams is very modest and does not make any conclusion based upon these assumptions without inserting a conditional clause. However, many points arise from consideration of this work on which I would like further details.

It is difficult to visualize how a minute amount of sulphur or oxygen will have one effect on iron, whereas a moderate amount of these two elements will have the reverse effect, and a large amount of the same two elements will produce the original effect once again. The factual evidence of this is clear enough from the experiments reported, but I think the explanation must be a little more complicated than is assumed by Mr. Williams.

The author has attempted to prove that oxygen is the active agent in varying the forms of the manganese–sulphide phase ; he has produced a large amount of circumstantial evidence, but I consider he has failed to prove it conclusively. I appreciate the difficulties of carrying out extensive gas analyses on cast iron, but would suggest that Mr. Williams should at least have attempted to obtain the oxygen content of some of the experimental irons he has been using. Also, the possibility that the effects are caused not by oxygen but by hydrogen or nitrogen must not be overlooked. In work of this kind, where the author has gone to considerable lengths to ascertain the purity of his raw materials, it seems a pity that the gaseous elements have been neglected.

The work on chill wedges is interesting, but I suggest is not sufficiently conclusive : chill-wedge tests with cast iron may often give misleading results. It would be of interest to know whether Mr. Williams carried out more tests than are reported in this paper and, if so, whether all these tests gave similar results.

Mr. Williams has used high-purity alumina crucibles in most of the work reported in this paper. Some of the observed effects have been caused by minute amounts of included aluminium. Is it not possible that in some of the experiments the alumina of the crucible has been reduced, giving a pick-up of aluminium in the metal ? If so, there may be a different explanation of some of the experimental results. Mr. Williams has suggested that the effect of aluminium was an indirect one, because of the deoxidizing nature of the aluminium addition. If the effect of aluminium was direct, could this explain some or most of the experimental results ? I suggest that the experiments on superheated and on vacuum-melted alloys are amenable to this treatment. Consider for example, the reaction $Al_2O_3 + 3C = 2Al + 3CO$. At and above 1400° C. this reaction is obviously very slow under original atmospheric pressure, but it could probably go more completely to the right under vacuum conditions. Moreover, the reaction would, presumably, go to the right with greater rapidity at the superheating temperatures. The result of this reaction would be a supply of aluminium available for solution in the iron even though aluminium had not been intentionally added to the melt.

It is stated that no aluminium was found, on spectrographic analysis, in those instances where aluminium had not been added, but it must be admitted that spectrographic analysis may not be able to detect the small amount of aluminium involved. In Fig. 76 of the paper it is shown that the sulphide inclusion in iron might be duplex, and it is just possible that the dark-etching phase in this duplex inclusion is an aluminium sulphide. I imagine that the author has considered the effect of contamination by refractories, and that he may have a satisfactory answer ; he might even have used other refractory materials to check the general trend of his results. If so, it would be interesting to have a brief statement on the subject.

The ring-like structures of graphite are particularly interesting, and Mr. Williams is to be congratulated on showing how these occur. I have once or twice noticed this structure in photomicrographs of cast iron, but I have never been quite certain that it really was graphite. Apparently this is yet another variety of graphite structure ; perhaps one day we might have a range of high-strength irons based on ' fish-eye ' graphite instead of ' nodular ' graphite.

Professor **R. W. Heine** (The University of Wisconsin, U.S.A.) wrote : On p. 420 reference is made to the effects of aluminium additions on the type of manganese sulphide inclusions which are present in white cast irons, and the author refers to the elongated or anchor type of sulphides (Figs. 40, 46, 48) as being those associated with complete deoxidation with aluminium as reported by myself. These are not the inclusions to which I

* C. Benedicks and H. Löfquist, " Non-Metallic Inclusions in Iron and Steel." London, 1930 : Chapman and Hall, Ltd.

† J. O. Arnold and G. R. Bolsover, *Journal of The Iron and Steel Institute*, 1915, No. I, pp. 217–274.

refer as the type present when deoxidation is complete with aluminium, *i.e.*, Type II inclusions. The inclusions which Mr. Williams has shown in these figures are those which are normally present in an undeoxidized iron, which I refer to, in a paper published in 1950, as Type I inclusions.* The Type II inclusions which I associate with complete deoxidation have a very different eutectic or film-type of distribution.† Perhaps my first work in this field did not make sufficiently clear the basic differences between these types of inclusion, and I trust that Mr. Williams' work and my work may be more compatible when these differences are understood.

With reference to the duplex type of inclusion, Type III, another important factor must be considered, *i.e.*, the temperature at which the molten iron exists prior to the aluminium addition. At 1400° C., which was the temperature employed by Mr. Williams for most of his work, I am not surprised that difficulty was encountered in obtaining duplex inclusions. I have found that it is necessary to have temperatures in the vicinity of 2800° F. to consistently produce Type III inclusions with aluminium additions. Our experience has been that, when temperatures in the neighbourhood of 2500° and 2600° F. are used, Type III inclusions do not appear, or appear to a limited extent, as was the observation of Mr. Williams in his paper.

AUTHOR'S REPLY

Mr. **W. J. Williams** said in reply: Mr. Hallett's interpretation of the ash analysis is quite correct. The figures given on p. 409 for the composition of the ash are based on the composition of the graphite.

Boyles studied the influence of small amounts of sulphur on the solidification of pure iron–carbon–silicon alloys, and the rate of cooling employed was such that the untreated alloys solidified grey. He found that as the sulphur content was increased the undercooled type of graphite which was obtained in the alloys containing very little sulphur became progressively coarser and then reverted to a fine graphite structure. Boyles suggested that the sulphur acts as a carbide stabilizing element throughout, and that with low sulphur contents the carbide tends to graphitize very rapidly, giving fine graphite. When the sulphur content is increased the carbide stabilizing effect is increased and decomposition of the carbide is slower, giving a coarser type of graphite. Further sulphur increases result in increased carbide stabilization, until graphitization is completely suppressed.

Mr. Bacon has drawn attention to sulphur segregation in large castings, and to the two types of sulphur prints which may be obtained, as described by Mr. Morrogh. It has been suggested that poor service life in heavy castings may be associated with the elongated type of manganese sulphide inclusions producing a greater discontinuity in the matrix than that produced by the compact inclusions. Mr. Bacon's observations on the service life of ingot moulds show that the better service life is associated with the elongated type of inclusion as revealed by sulphur prints. I think that the shape of the manganese sulphide inclusions provides some indication of the nature of the iron matrix, particularly with respect to the combined carbon content, which may vary considerably in heavy castings.

In reply to Professor Thompson, I have commented briefly in the paper on the duplex nature of the sulphide inclusions produced as a result of large additions of aluminium to cast iron. A dark angular inclusion is frequently found surrounded by manganese sulphide, and although there is some evidence to suggest that the dark phase is hercynite (FeO, Al_2O_3), the true nature of these inclusions may not be known until a method of extraction and chemical analysis has been developed to support the micrographic evidence. Such methods are being studied at the laboratories of the B.C.I.R.A.

AUTHOR'S WRITTEN REPLY

Mr. **Williams** wrote in further reply: In regard to the points raised by Dr. Riley on the effect of the small amounts of sulphur and what is considered to be oxygen, it should be realized that I have not attempted a simple explanation of this phenomenon, and until some quantitative information is obtained on the distribution of these elements in the melt, it would be unwise to state anything more than the experimental procedure and results obtained.

Dr. Riley suggests that more attention should have been given to the gaseous elements, when considering the effect of oxygen on the manganese sulphide inclusions. The absence of this information was fully realized throughout, and it is unfortunate, as Dr. Riley will readily appreciate, that methods for the determination of the oxygen content of cast irons have not, up to the present, reached a satisfactory degree of reliability and accuracy. Furthermore, the oxygen content of a melt immediately following deoxidation with aluminium would probably be the same as that of the melt immediately prior to the aluminium addition, whereas the effects are totally different.

With regard to the reliability of chill wedge tests, there may be slight differences from one wedge to another owing to uncontrolled factors, but the extensive changes repeatedly produced by inoculation and aluminium additions are entirely outside the range of any small deviations during the routine use of a chill test.

The possible contamination of the melts with aluminium, as a result of the reduction of the alumina crucibles by the carbon in the melts, was investigated. Spectrographic analysis failed to detect aluminium in the air-melted ingots unless the aluminium was deliberately added. Pure iron–carbon melts were then held for 1 hr. in an alumina crucible *in vacuo* at temperatures of 1400–1800° C., approx. Aluminium was not detected spectrographically in melts held at 1400° C., but approximately 0·2% of aluminium was found in the melt held at 1550° C. (approx.), and 0·87% of aluminium in the melt held at 1800° C. (approx.), with corresponding reductions in the carbon contents.

As the gaseous products of the reaction $Al_2O_3 + 3C = 3CO + 2Al$ are completely removed *in vacuo*, the reaction would be expected to proceed further to the right *in vacuo* than in air. The reduction of Al_2O_3 *in vacuo* at 1400° C., if undetected by spectrographic analysis, would be less likely when melting at 1400° C. under oxidizing conditions.

It is not clear why the compact type of manganese sulphide inclusions should form at superheating temperatures. This type of inclusion, as shown in Figs. 49 and 50, is different from the other compact type of inclusion formed by low melting temperatures and illustrated in Fig. 47. The former are similar to the inclusions formed by aluminium additions, inoculation with ferro-silicon, etc., and also vacuum melting, whereas the latter are much bigger and rather more angular in shape. This type (Fig. 47) is believed to be due to oxidation, the elongated type shown in Fig. 48 to a lesser degree of oxidation, and the compact type (Figs. 49 and 50) to a further reduction in oxidation.

The answer to Dr. Riley's question whether the effect

* R. W. Heine, University of Wisconsin Engineering Station, 1950, Reprint No. 156.

† *Loc. cit.*

of aluminium on the sulphide inclusions is direct or indirect is given on p. 413, under the heading " Influence of Vacuum Melting on the Form of the Manganese Sulphide."

I regret the misinterpretation of Professor Heine's results, this being due to a confusion, on my part, of the terms ' elongated ' as used by myself to describe the type of inclusion associated with partial deoxidation, and ' film-type ' as used by Professor Heine to describe the type of inclusion associated with complete deoxidation. This will be apparent from Professor Heine's contribution, *viz.*, " The Type II inclusions which I associate with complete deoxidation have a very different eutectic or *film-type* of distribution." Professor Heine's comments on the formation of Type III inclusions are greatly appreciated.

Joint Discussion on the Papers—

THE THERMODYNAMIC BACKGROUND OF IRON AND STEEL MAKING PROCESSES. Part I—THE BLAST-FURNACE*

By F. D. Richardson and J. H. E. Jeffes

and—

THE INFLUENCE OF GAS/SOLID TEMPERATURE DIFFERENCES ON BLAST-FURNACE OPERATION†

By J. Taylor

Mr. **J. H. E. Jeffes** (British Iron and Steel Research Association) presented the first paper, and apologized for the absence of his co-author, Dr. **F. D. Richardson,** who was in America.

Dr. **J. Taylor** (Royal Technical College, Glasgow) presented the second paper.

Mr. **R. A. Hacking** (Richard Thomas and Baldwins, Ltd.): Mr. Jeffes remarked that when the authors embarked on this thermodynamic investigation of the blast-furnace process they became appalled by its complexity. Everyone concerned with practical operation or with theory will heartily endorse that opinion, and will be thankful that, in spite of this maze of internal intricacies and unknown or only partly understood factors, the blast-furnace still stands supreme as the most efficient appliance for the reduction of iron ores to metal.

Attempts to determine what is going on inside the blast-furnace date back nearly a century, but the rate of progress has been greatly accelerated during the last thirty years. The authors refer to the work of the Field Tests Panel, in 1937, on one of the Frodingham furnaces, but omit reference to the earlier comprehensive investigations of Joseph and his co-workers of the U.S. Bureau of Mines, relating to their small experimental furnace at Minneapolis,* and later to full-scale units in Alabama† and Illinois.‡ The iso-CO_2, isothermal, and iso-velocity diagrams relating to the last-named furnace (operating on Lake ores) would have provided the present authors with a yardstick more in keeping with modern standards, and would have lessened the contrast between their quoted CO/CO_2 ratio in the exit gas (3 : 1) and the 1½ : 1 assumed by Dr. Taylor.

Hitherto, the experimental work and resultant discussion on the blast-furnace process have given us a general picture of what reactions are proceeding, and which tend to predominate at the various levels in the stock column. This, however, appears to be the first occasion on which the urge behind each reaction has been quantitatively expressed, and the authors are to be congratulated on setting down, in so interesting and ingenious a form, factual information which will be of great value to the industry. However, I have found some difficulty in reading the CO/CO_2 ratio with even reasonable accuracy on the logarithmic scale. As Dr. Taylor rightly points out, in this ratio we have the concise expression of blast-furnace efficiency, but in the authors' diagrams the CO/CO scale appears to be much too coarse for convenient use.

An interesting point brought out in the paper by Richardson and Jeffes is that phosphorus transfer from phosphate to iron can, and probably does, take place mainly *via* the gas phase, and that this may be a possible explanation of the completeness of phosphorus recovery in the metallic product. On p. 407 the authors refer to the steep rise in the ' lowest B.F. gas line,' at temperatures between 800° and 600° C. They ascribe this sudden decrease in CO/CO_2 ratio to the more rapid onset, at that temperature, of carbon deposition, rather than to more rapid reaction between the gases and the ores. This hardly agrees with previous experimental work in this temperature range, and appears also to overlook the authors' following paragraph relating to the decomposition of carbonates.

Referring to alkali reduction, McConnachie‡ enunciated a theory of the function of elemental sodium and potassium, and their cyanides, in effecting the last stages in the reduction of iron, manganese, silicon, phosphorus, etc., in the hearth of the blast-furnace. At the time he had little practical or theoretical evidence in support of his theory, and I imagine that most of his listeners were frankly sceptical. However, Richardson and Jeffes' thermodynamic treatment of the question now shows that the existence of alkali-metal vapours in the

* P. H. Royster, T. L. Joseph, and S. P. Kinney, *Blast Furnace and Steel Plant*, 1924, vol. 12, pp. 35–38, 98–100, 200–204, 246–250, 274–280.

† S. P. Kinney, P. H. Royster, and T. L. Joseph, United States Bureau of Mines, 1927, Technical Paper No. 391.

‡ S. P. Kinney, *Ibid.*, 1929, Technical Paper No. 442.

* *Journal of The Iron and Steel Institute*, 1949, vol. 163, Dec., pp. 397–420

† *Ibid.*, 1950, vol. 164, Feb., pp. 129–140.

‡ W. McConnachie, *Proceedings of the Cleveland Institution of Engineers*, 1931–33, pp. 164–179.

blast-furnace hearth is not only possible, but probable.

In regard to the part these phenomena may play in scaffold formation, I would like to refer to ferromanganese practice, in which the throughput of alkali metals, particularly when using certain Indian and other manganese ores, may be relatively much higher than in basic iron practice. I have never experienced or heard of scaffolds arising from accretions of compounds of the alkali metals, in any furnace making ferromanganese. The explanation may be that the high shaft temperatures obtaining preclude deposition, on the shaft walls, of alkali complexes resulting from re-oxidation of metallic vapours rising from the hearth. It is certain, however, that the flue dust produced in ferromanganese practice, and particularly the lighter fractions, is characterized by remarkably high contents of potassium and sodium compounds.

The term 'direct reduction' to which Dr. Taylor refers has come to be regarded by many blast-furnace technologists as something which is invariably detrimental to thermal efficiency—a most erroneous view. The author stresses the fact that in rich-ore practice a definite and, indeed, large proportion of direct reduction is essential to maximum efficiency and minimum coke consumption. In some of the author's hypothetical cases, the percentages of direct reduction appear to be remarkably high; but if the assumptions necessarily made have resulted in exaggeration of what is happening in full-scale practice, so much the better if they enable the point to be driven home. Dr. Taylor's thermal analysis, stage by stage, brings out another important point. In the lean-ore practice which comprises so large a part of British production, Grüner's ideal is still the target, and direct reduction is something to be avoided, this being more difficult in lean-ore conditions because of the lower reduction potential of the gas. This underlines the greater need for physical preparation of ores in lean-ore as compared with rich-ore practice.

The author's suggestion regarding the injection of coke-oven gas through the tuyeres of a blast-furnace, to smooth out the gas/solid temperature differences and generally to control the slope of the thermal curve from the tuyeres to the bosh level, is most interesting, but in an integrated works it would lead to some complications. I assume that the figure of 7%, which he uses for calculation, is 7% by volume of the blast. Applied to normal amounts of coke-oven gas arising, and air blown, for a balanced production within an integrated works, this figure would represent a substantial and even crippling interference with the gas-distribution system, particularly from the qualitative (as distinct from the overall quantitative) point of view. Perhaps the author has used the high figure of 7% to obtain a decisive answer and to underline the effect of coke-oven-gas injection, but at the same time he should bear in mind the question of availability.

Dr. Taylor does not mention the use of steam (at a blast-furnace plant in the U.S.A. during the war) to achieve, by automatic injection, blast of constant moisture content. Some of the early economies achieved by the use of dried blast were ascribed, not so much to the fact that the blast was indeed dry, as to the fact that one more variable—humidity—had been smoothed out from the operating conditions.

The trouble about dry blast has always been the cost of the drying operation itself. The figures quoted by Dr. Taylor, which I think are reasonable, show that the use of dry blast would not be a profitable proposition in Britain. In tropical countries I believe a case could be made out for it, since it would smooth out the enormous differences in humidity which occur seasonally and between day and night conditions.

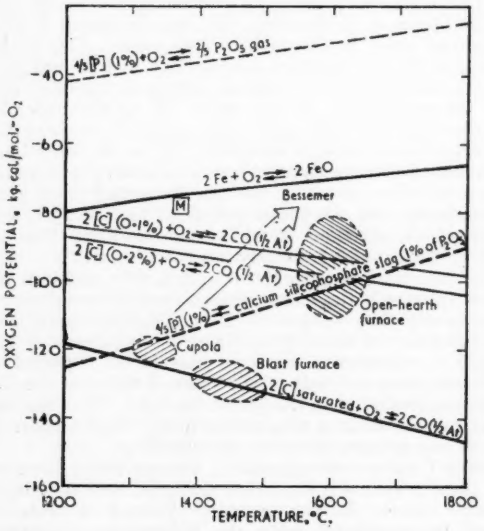

Fig. A—Approximate working areas in temperature and oxygen potentials of the principal iron and steelmaking units, in relation to phosphorus oxidation

Sir **Charles Goodeve** (British Iron and Steel Research Association): The basic information given in the paper by Richardson and Jeffes puts the theory of the chemical reactions in a blast-furnace on a firm foundation. Much still remains to be done, however, both in the more precise determination of the data and in the application of the information to works practice.

It is at first sight surprising that the weakest part of our knowledge should concern phosphorus, one of the most important elements requiring control in iron and steel making. This is perhaps partly due to the complexity of the phosphorus compounds. However, the general thermodynamic picture is known sufficiently accurately to permit certain conclusions to be drawn. Figure A shows this in a simplified form. The potential of oxygen in liquid iron can never rise above the Fe ⇌ FeO line, as the iron would simply burn. In the presence of carbon monoxide, say ½ atm. partial pressure, it can never fall below the C ⇌ CO line, because carbon would precipitate as graphite and CO would dissolve and dissociate. In the absence of CO one can 'kill' oxygen potentials down to much lower levels, such as those shown in Richardson and Jeffes' Fig. 5 for Si and Al.

The actual oxygen potential in iron, at any stage in iron or steel making, is more controlled by the carbon content than by the carbon monoxide pressure. In the blast-furnace it can never rise much above the C ⇌ CO line, owing to the presence of coke, and accordingly the range of values is limited to the small area shown. In the open-hearth furnace a much greater range is possible, but during the refining period the whole of this range lies much higher than that for iron in the blast-furnace. The range of the Bessemer converter making low-carbon steel is even greater, as is indicated roughly by the arrow.

The approximate position for the phosphorus oxidation line in a basic slag is shown broken, partly because of the uncertainty in the data and partly because of the variable conditions that might exist. It will be noted that lime, through its affinity for P_2O_5, has brought the phosphorus oxidation line a very long way down from

its level when the product is P_2O_5 gas. This line is representative of a family of lines for other concentrations of [P] and (P_2O_5), the lines for lower [P] and/or higher (P_2O_5) lying above this line, and the opposites lying below.

Remembering the simple rule that oxygen, like electricity, can only flow from a higher to a lower potential, one sees why phosphorus can be oxidized out of iron in the open hearth and in the Bessemer converter but not in the blast-furnace or in the cupola. Indeed, if some calcium phosphate was produced because of local high oxidizing conditions, it would later be reduced by carbon in contact with the slag, sending phosphorus back into the iron, or it might pass back through the gas phase, as suggested by Richardson and Jeffes.

To what extent, and in what ways, is it worth while attempting to remove phosphorus from iron before it reaches the open-hearth furnace ? If phosphorus is to be removed by oxidation then the oxygen potential of the iron in contact with the slag must be brought *above* the phosphorus oxidation line. It is seen from Fig. A that the normal region for blast-furnace iron is a long way below the probable position of this line. Some lowering of the temperature into the region of cupola metal would help, but the chief requirement is for the discovery of a cheap material with an affinity for P_2O_5 much greater than has lime. From the accumulated knowledge of phosphorus compounds this possibility looks rather remote. A raising of the oxygen potential of blast-furnace iron can only be effected by removing carbon, or by operating at extremely high pressures, perhaps a few hundred atmospheres !

This treatment of the problem is very much simplified, and for accuracy would require modification in a number of ways. It does, however, lead to a much more pessimistic view of the possibilities of removing phosphorus without removing carbon than that held by Kerlie.* The apparent conflict between the number of rather isolated experiments in which phosphorus is claimed to have been removed from iron containing 2–4% of carbon, and the theoretical conclusions reached here on thermodynamical grounds, demand much further study. No chemical method for the removal of phosphorus other than by oxidation can be envisaged, but perhaps another somewhat academical possibility might be mentioned : that of removal by distillation in an inert gas such as argon.

Dr. **H. L. Saunders** (Imperial College of Science and Technology) : Strictly speaking, there is no such thing as a temperature level in the blast-furnace. There is a gradient from top to bottom, one from the centre to the wall, and one from the outside to the inside. However, the main object of research is to increase our knowledge of a process by any available means, and any legitimate line of approach is valid.

Although a great deal can be learned by theoretical calculations on the basis of certain assumptions, this information should be supplemented by actual observations from the interior of the furnace ; it is not until these observations have been made, and analyses of gas and solid material taken from definite layers at many points, that our picture of the internal conditions will be really complete and satisfactory. Perhaps the most serious gap in our information is in the question of the ratio of direct to indirect reduction, and much depends on this factor. Dr. Taylor points out that for equal efficiencies the proportion of indirect to direct reduction should be greater with high slag volumes, and also that indirect reduction is more difficult, because of the lower reduction potential of the gas in those cases. It is fortunate that our lean home ores are in the same category as regards reducibility as some of the foreign hematites, and are certainly greater than the magnetites.

There is another question which involves a possible extension of this argument. Both reduction potential and heat transfer should be considered in relation to the contact time between the reactants, because a gas of the same composition will naturally behave very differently according to whether it is stagnating or violently channelling in the furnace. Perhaps Dr. Taylor will one day extend his efforts in that direction, to include time as an additional factor.

B.I.S.R.A. is also working on this problem of heat balances at different temperatures. We are hoping to take temperature increments as small as 50° C. in some cases. At the moment we have in mind a rather elaborate mechanical aid, something like a multiple slide rule, which will give a complete and detailed picture, immediately visible, so that we can make any necessary adjustments and see the effect of these at once, without having to go through numerous calculations for each correction. Our present efforts have been confined to the arithmetical side, and we have been a little surprised to see the small separation between the curves of burden heat requirements and availability of heat in the reducing gases for widely differing practices ; we feel there may be some factor still lacking.

It seems to me that further direct experiment is required on the actual furnace by, say, the employment of mechanical probes to penetrate and extract material from the inside, with corresponding temperatures and analyses. This would be the most favourable line of attack to expand the already growing mass of information on the blast-furnace.

Dr. **T. P. Colclough** (Ministry of Supply, Iron and Steel Division) : Richardson and Jeffes' paper on the thermodynamic aspects of the subject is very welcome, because such information has been sadly lacking. Taken in conjunction with a paper* published in America this year, there is now a fairly safe basis on which to found our speculations.

The paper by Dr. Taylor is a little more after my own heart, because it describes the way in which I have attacked these problems for many years. Dr. Taylor has started from certain assumptions and proved that the assumptions were right according to the rules that he has laid down. If one starts off, as the paper by Richardson and Jeffes does, with a CO/CO_2 ratio of 3/1, a certain set of facts is obtained. If, on the other hand (having the thermodynamic data in mind), an equilibrium of 1/1 is possible, one can formulate one's ideas accordingly and can adopt a basis of $1\frac{1}{2}$/1, or $2\frac{1}{2}$/1, that will set the standard at which one can aim. The old idea of a ratio of 3/1 is today not good enough.

I must disagree with Mr. Hacking, who said that the blast-furnace is the most efficient piece of metallurgical equipment that we have. A blast-furnace may have an efficiency of 95–97% so far as the reduction of iron oxide is concerned, but how can it be regarded as efficient when one-half of the thermal value of the fuel charged comes out in the gas at the top ? Now that the cost of coke is £4 a ton, and is likely to go higher, we must pay primary attention to efficiency.

May I make one suggestion ? The problems discussed in these papers are extremely complex, and it is not a simple matter for the ordinary operator or technical man to apprehend fully the information presented. Is it possible to arrange a series of meetings at which

*W. L. Kerlie, *Journal of The Iron and Steel Institute*, 1947, vol. 157, pp. 173–182.

*C. J. Osborn, *Journal of Metals*, 1950, vol. 188, Mar., pp. 600–607.

these subjects can be discussed in detail and a more complete understanding obtained ?

Mr. S. Klemantaski (British Iron and Steel Research Association) : In discussing the effects of additions of steam or of coke-oven gas, Dr. Taylor has not taken into account the stimulating effect of hydrogen on the carbon-deposition reaction, a reaction important for the heat balance both directly through its strongly exothermic nature and indirectly through its influence on other chemical and physical processes. It is possible that the inhibitors of carbon-deposition present in coke-oven gas may counter, to some extent, the effect of hydrogen.

The omission of any reference to the work of Reichardt* seems regrettable, as this author was one of the first to consider, in detail, thermal supply and demand in the blast-furnace.

If the CO_2/CO ratio is taken as the measure of the efficiency of blast-furnaces, the process is seen to be grossly inefficient, since at normal top temperatures this ratio is very high for gases in equilibrium with either ferric oxide or carbon.

Dr. **T. E. Dancy** (British Iron and Steel Research Association) : There are two points I would like to make, both referring to Dr. Taylor's paper. The assumption that direct reduction does not take place below 900° C. is borne out by experimental work carried out at Imperial College. Using the technique of differential thermal analysis, the reactions between a number of forms of carbon (including a variety of cokes, and graphite) and both magnetite and hematite ores have been studied. In all these cases very little reaction occurred below 900° C. (carbon-impregnated ores excepted).

The other point concerns the reduction of FeO, which, as Dr. Taylor states, is probably complete by the time the 1350° C. isotherm is reached. The reduction of FeO, besides being brought about when FeO-rich slag passes over coke, can also occur when carbon-rich iron comes into contact with FeO. Since the latter provides better contact between carbon and oxide, it would be expected to be a faster reaction than the former, and experiments in the laboratory have shown this to to be true. In addition, the reduction of magnetite by carbon in molten iron is considerably slower than any reduction of FeO at the same temperature. Thus when quantities of magnetite ore are used in the burden, it is likely that unreduced iron oxide may exist at temperatures higher than 1350° C.

CORRESPONDENCE

Dr. **J. Taylor** (Royal Technical College, Glasgow) wrote : Comparatively few experimental data are available on many of the important reactions taking place in the blast-furnace. This paper by Richardson and Jeffes presents for the first time, in an easily appreciated form, all the available thermodynamic data pertaining to blast-furnace reactions. As was stated by the authors, the derived equilibrium data give activities and not concentrations. For all those high-temperature reactions in which the reactants are present as slag or metal solutions, activity coefficients are necessary to convert activities to concentrations. Data on activity coefficients are very meagre, and one or two speakers in the discussion seemed inclined to claim more than the authors ; but this in no way detracts from the value of the paper.

The authors themselves have not been quite proof against the temptation to draw positive conclusions from insufficient data. For instance, in dealing with the silicon and sulphur reactions, calculations have been made to illustrate the effect of temperature. The results are given as activities, but it is suggested that the variation of activity coefficient with temperature is so small that, comparatively, they apply to concentrations also. This gives the rather surprising result that an increase in temperature from 1400° to 1500° C. increases the [Si] concentration 25–30 times. In fact, it can be calculated from data given by the authors that the activity coefficient of Si in iron increases 1½ times between 1400° and 1500° C. If there is a similar increase in (CaO), which is quite probable, the increase in the equilibrium [Si] is not 25–30 times but only 8–9 times. Similar considerations could be still more important for the variation in [S], the calculated ratio being 3 : 2 for an increase in temperature from 1400° to 1500° C. Variations of activity coefficients with temperature would most probably increase rather than decrease this difference, but until this is proved it seems rather bold to say ' the significant effect of temperature in raising the proportion of the sulphur in a slag of fixed lime activity and in lowering the concentration in the metal is immediately evident.'

More important are the deductions made from the calculated activities of (MnO), (SiO_2), and (CaS) in the slag, corresponding to concentrations of 1% of Mn, 1% of Si, and 0·1% of S, respectively, at 1480° C. It is concluded that, in general, [Mn] and [Si] in the metal are less than the equilibrium value and [S] is greater, so that Si and Mn are transferring from slag to metal and S from metal to slag in the well of the furnace. The calculations are based on equilibrium with solid carbon, for which the activity of (FeO) should be about 0·001. There is some reason to believe that this is quite difficult to attain, even in the laboratory, and in practice FeO contents of 0·5% and over are common, although the concentration at the slag/metal interface is probably less than the average for the slag layer as a whole. It seems rather unreal, therefore, to base these calculations on the C–CO oxygen potential rather than on that of an FeO-containing slag. The very marked effect of the FeO content is shown by the activity values calculated for a 0·17% FeO slag. These are : for MnO 0·05, for SiO_2 0·32, and for CaS/CaO 13, compared with the values 0·01, 0·01, and 68, given in the paper. Translation of these values into concentrations is impossible without the appropriate activity coefficients, but taking possible values it could be argued that, normally, [Mn] is close to the equilibrium value but [Si] and [S] are above. This would imply that transfer of Si in the well of the furnace is from metal to slag, and not *vice versa*. On this assumption there must be a transfer of Si from slag to metal above the slag pool and probably as vapour in the high-temperature region opposite the tuyeres.

This theory of the course of silicon reduction is in accordance with the views advanced by Wüst, 25 years ago. It also receives some support from the results of Mund, Stoecker, and Eilender,* who carried out what still appears to be the most accurate and exhaustive study of the conditions in the hearth and bosh of a furnace. The hypothesis is speculative, but not more so than that advanced by Richardson and Jeffes. Again, the authors' conclusion that ' fluctuations in temperature and slag thickness must be the main cause of the variations in [Si] and [S] ' seems rather too confident. On the alternative hypothesis the tuyere combustion zone plays a vital part in determining [Si] values.

* P. Reichardt, *Archiv für das Eisenhüttenwesen*, 1927–28, vol. 1, pp. 77–101.

* A. Mund, J. Stoecker, and W. Eilender, *Stahl und Eisen*, 1931, vol. 51, No. II, pp. 1449–1462.

One final point: there is, I think, a slip on p. 411. Surely the temperature of the slag layer decreases, not increases, from top to bottom.

This paper has pointed the way to a more complete knowledge of blast-furnace reactions; but many more data are required on conditions in the hearth and bosh of the furnace, as well as on activity coefficients in slag and metal solution, before much practical use can be made of the thermodynamic data contained in the paper.

Mr. **C. E. A. Shanahan** (British Iron and Steel Research Association, Sheffield) wrote: In regard to the paper by Richardson and Jeffes, I would like to draw the authors' attention to a laboratory investigation performed in America by Birchenall and Philbrook,* into the amount of Ca metal absorbed by molten pig-iron from blast-furnace-type slag. These workers introduced radio-Ca as CaO into the slag, and made subsequent radioactivity measurements on the molten iron. They concluded that the iron contained less than 6×10^{-5} % of dissolved Ca. This result is probably in agreement with the authors' data. Thus, assuming the operating oxygen potential is $-119{\cdot}0$ kg.cal. at 1400° C., *i.e.*, corresponding to the C–CO line at 1400° C. at a pressure of 2 atm. ($p_{O_2} = 2{\cdot}95 \times 10^{-16}$ atm.), it follows from the authors' data that CaO of unit activity would be in equilibrium with Ca of activity $1{\cdot}53 \times 10^{-7}$. If it is also assumed that the solution of Ca in liquid iron is ideal, and that there are no inter-solute effects involving carbon, silicon, manganese, etc. (*i.e.*, that the activity coefficient of Ca is unity), then the amount of metallic Ca dissolved in the blast-furnace iron would be of the order of 10^{-5} %. This figure would be smaller in practice, owing to the non-attainment of equilibrium and the CaO activity being less than unity. The tapped metal would contain even less dissolved Ca, as a consequence of the fall in temperature and increase in oxygen partial pressure.

AUTHORS' REPLIES

Dr. **F. D. Richardson** and Mr. **J. H. E. Jeffes** wrote in reply: We wish to express our appreciation of the useful information and criticism which have emerged from the discussion and from correspondence. Mr. Hacking's suggested explanation for the rise of the 'lowest B.F. line' between 800° and 600° C. is attractive, and may well be more important than the one suggested by us. His comments on ferromanganese manufacture from ores with high alkali metal contents are most interesting, particularly as it is so difficult to obtain reliable information about the effects of alkali metals on blast-furnace performance.

We agree, in general, with Dr. Taylor's comments, which are of great value, and also that we may have erred occasionally on the side of suggesting conclusions rather firmly when the data have been scanty. We have, however, done this with the intention of showing just how far one may expect to progress with a thermodynamic treatment of the type put forward. In regard to the particular points raised by Dr. Taylor concerning the partition of elements such as silicon and sulphur, we must emphasize that, as stated in column 2, p. 411, the manner in which the activity relationships varied with temperature gave an *indication* and not a precise measure of how the concentrations would themselves be expected to vary. His calculations on the theoretical effect of 0·1–0·2% of FeO in the blast-furnace slag on the slag/metal equilibria with respect to sulphur, manganese, and silicon, are useful. We consider, however, that they may be more representative of conditions in the upper part of the slag than near the slag/metal interface. Indeed, they suggest that, whereas sulphur probably moves from metal to slag throughout the whole time of contact between them, silicon may move from metal to slag in the upper part of the slag, and from slag to metal in the lower.

Mr. Shanahan's calculation concerning Ca and CaO activities is of interest. Large allowances must obviously be made for the low activity coefficient of the lime in the slag and a high activity coefficient of calcium in liquid iron, so that the results of the experiments made with radioactive calcium in no way conflict with our conclusions.

Dr. **J. Taylor** wrote in reply: I would agree in general with Mr. Hacking's remark about direct and indirect reduction, only pointing out that direct reduction should be kept to a minimum in all types of practice but that this minimum is much less in lean-ore practice. The values given for direct reduction are not assumed but are calculated (ref. 1) for the given conditions; if anything they are underestimated, because it is now known that the value taken for radiation and cooling losses was much too high for modern practice. The injection of coke-oven gas or steam was considered purely from the technical point of view, but Mr. Hacking is quite right in pointing out the many other considerations that would arise in practice.

It is interesting to note that the addition of steam to air blast up to a humidity of 12–14 grains/cu. ft. to cure hanging has been reported by Fulton.*

Dr. Saunders rightly stresses our lack of knowledge of conditions inside the blast-furnace, and the variation of temperature at any horizontal level in the furnace. He might also have stressed the difficulty of obtaining solid samples from an operating furnace. Meanwhile, I think he agrees that useful comparative information may be obtained from the study of a simplified version of the process.

Dr. Colclough's remarks about the top gas CO/CO_2 ratios are appreciated, but I feel it is not really possible to use equilibrium values from thermodynamic data as the criterion of efficiency without knowing a great deal about the kinetics of the reduction at temperatures of 200–400° C.

Mr. Klementaski raises the question of the carbon-deposition reaction. This is a catalytic reaction, and like all such is so sensitive to the physical condition of the surface of the catalyst that I feel it is impossible to form any worth-while opinion as to the effect of varying conditions.

Dr. Dancy suggests that magnetite may exist unreduced at temperatures above 1350° C. This is probably so for pure Fe_3O_4, but with the normal minimum of impurity it should be fluxed to form a primary slag at or below this temperature, and such slags are reduced very rapidly in contact with carbon.

*C. E. Birchenall and W. O. Philbrook, *The Iron Age*, 1949, vol. 164, No. 19, p. 77.

*L. M. Fulton, *Journal of Metals*, 1950, vol. 188, Mar., pp. 476E–480.

Joint Discussion on the Papers—

BLAST-FURNACE GAS CLEANING. AN ANALYSIS OF PLANT PERFORMANCE*

By R. F. Jennings

and—

BLAST-FURNACE GAS CLEANING. METHODS FOR CALCULATING THE MOTIONS OF PARTICLES IN A GAS†

By J. Stringer

Mr. R. F. Jennings (British Iron and Steel Research Association) and Mr. **J. Stringer** (British Iron and Steel Research Association) presented their respective papers.

Mr. N. H. Turner (Appleby-Frodingham Steel Co.): Mr. Jenning is right when he contends that the design of gas-cleaning equipment is basically empirical, and that little is known of the true methods of operation. Too much use of rule-of-thumb, or lack of full appreciation of the conditions under which the plant is to operate, have sometimes resulted in plant being quite incapable of fulfilling the specification. In support of the need for more knowledge, I cannot do better than mention two experiences at Appleby-Frodingham.

The first relates to bag-filter-type gas-cleaning plants. The main units of these plants, nominally capable of operating at 1,250,000 cu. ft./hr., were never capable, in spite of the makers' efforts, of passing more than 70% of this output while still maintaining a life of bag within the specification. A special investigation carried out after some years of operation, to try to establish the cause of that inefficiency, led to the development of an entirely different technique of operation, and has since permitted the plants to operate in a very satisfactory manner from the points of view of gas-cleaning output and life of bag.

The second experience occurrred just before the war, when a set of four new disintegrators was installed, each to operate at approximately 3,000,000 cu. ft./hr. with a power consumption of some 460 h.p.; each disintegrator was found to require a further 230 h.p. to fulfil this duty. Alteration by the makers, which consisted of removing every other bar from the stator and every other bar from the outer ring of the rotor, produced a very marked decrease in power consumption; approximately 250 h.p. less was required for the same performance under the same conditions, and within the error of assessment the gas-cleaning efficiency was not affected at all by the modification.

A third fact, which has a bearing on the reference to rule-of-thumb methods, was that the four disintegrators, which were supposed to be identical, each had a different power consumption after the modification. The difference between the best and the worst was of the order of 10% over most of the output range. On the other hand, the pressure lift curves were the same for all of them.

The people responsible for the operation of cleaning plants can help considerably to remedy some of the trouble encountered, and time spent in assessing the effects of the various factors involved will go a long way towards promoting efficient operation. The amount of water used in scrubbing or in the disintegrator often remains constant, in spite of appreciable variation both in the amount of gas and the dust content, and seldom is the relation between the pressure drop across the bag and the life of the bag ascertained to find the most efficient point of operation.

Whilst I do not want to challenge the figures quoted for the cost of operation of the various plants, I feel these costs should be established on the same basis, bearing in mind the possibility, with some of these plants, of complete utilization of pressure energy, and with other plants, of a dissipation of part of the energy to no purpose. The present tendency for higher blast-furnace pressures makes it all the more necessary to consider this point.

In conclusion, I would mention some of the drawbacks met with in the operation of the plants with which I am acquainted. One of the defects of the dry gas-cleaning plant is the difficulty of keeping a close check on the state of each bag, so that at times the clean gas may be slightly less clean than is intended. Collecting the dust sometimes gives rise to the problem of fire prevention, because of spontaneous ignition. Although the cost of bag-filter cleaning may be comparatively low, the limitation on the use of this type of plant is likely to increase, following developments in blast-furnace ore and fuel preparation which may lead to the use of tar, the vapour of which would affect the texture of the bags in the same way as oily metal turnings fed to the blast-furnace have been known to affect the filter bags of a plant. On the other hand, an important disadvantage of wet plants, in which the cleaning water is recirculated after settling, is the rehardening of that water by the carbon dioxide of the blast-furnace gas. Even when the water has been initially treated, it will not be many years before the water mains to the gas plant are affected to a large extent.

Mr. **J. F. R. Jones** (John Summers and Sons, Ltd., and Chairman of the Fuel Committee, B.I.S.R.A.): The amount of water at present used in wet gas cleaning is very considerable, and is of the order of 40 gallons per 1000 cu. ft. of gas. The space occupied and the capital cost of gas-cleaning plant are also very large, and may or may not be usefully reduced by improved designs. Present methods give very satisfactory results, but it is felt that this should not exclude the examination of all possible economies by the use of new types of cleaner.

I would like to ask whether it is thought impossible in future to clean gas to a suitable degree of cleanliness without loss of heat. It would be worth while to consider the use of a gas turbine, with high top-pressure blowing, as, if it could be used, it should result in great economy in blast-furnace operation.

Dr. **R. Jackson** (British Coal Utilization Research Association): I wonder whether Mr. Jennings has any information about the performance, under these conditions, of the so-called aerodynamic or slotted-cone type of gas cleaner. I understand that the performance is similar to that of a cyclone, but the pressure loss is considerably less.

I am very glad to see that he emphasizes the relation between efficiency of collection and the size of the particle. The overall efficiency is an easy figure both

* *Journal of The Iron and Steel Institute*, 1950, vol. 164, Mar., pp. 305–325.

† *Ibid.*, pp. 294–304.

to obtain and to grasp, but it will vary very much with the type of dust and the burden. Most of the disagreements about the efficiency of dust collectors probably arise from a failure to state the size of the dust being collected. Values of efficiency varying from 50% to 95% have been quoted for similar equipment when the types of dust collected were dissimilar, and the detailed statement given in Tables II and III of his paper is an example, I think, of how the efficiency ought to be described.

A surprising feature of Table III is the flattening off of the extraction efficiency of the electrostatic precipitator with the diminishing size of the particle. One would expect, theoretically, that the efficiency would tend to rise almost to 100% as the particle size decreased. Has Mr. Jennings any explanation to offer of why this does not occur? I suggest that the error may be in the determination of the values. I am not clear what method was used to obtain these results; possibly some form of filter was used to collect the dust sample from the duct, and errors may then occur from a number of causes, among which are the possible shortcomings of the filter as a 100% collector of dust and the difficulty of getting the dust out of the filter once it has been collected.

I think the author underestimates the difficulty of obtaining a true sample from the gas stream. There are conflicting reports on the efficiency of the disc baffle and other types of device for obtaining single-point sampling. I agree, however, with his statement of the difficulties of determining the size distribution of the sample once it has been obtained.

Mr. **W. B. Wright** (Colvilles, Ltd.): Every effort should be made to reduce the cost of gas cleaning, which is about £1,250,000 per annum. Before the war, the disparity between the cost of cleaning by electrostatic and disintegrator methods was not such a serious matter as it has become today owing to the increased cost of fuel, so that there is much to be said in favour of the electrostatic method. During the last ten years the electrostatic technique has greatly improved, but there has been a tendency, because of the desire to reduce power costs, to underestimate the operational irregularities of these plants.

Mr. Jennings states that the performance of the precipitator is closely dependent on the rate of flow through the plant, and that the rate has a particularly large influence because the mechanism of operation is based directly on the separating velocity imparted to the dust particle in comparison with the speed of the gas stream through the plant. This is certainly true, and when such a plant is connected to a temperamental apparatus such as a blast-furnace, it is easy to see why the performance of precipitators is affected and cleaning irregularities result. The advocates of such plants do not sufficiently emphasize that it is necessary to isolate sections at frequent and often short intervals, to remove build-up of dust between the discharging and the collecting electrodes.

In spite of the adverse criticism which many people level at the use of disintegrators, I am glad Mr. Jennings has suggested that replacing the methods of design of the past by a scientific investigation of the problem may not compromise many of the advantages of the disintegrator, and may greatly reduce the power consumption. His suggestion that most of the useful work may be done on the periphery of the outer rotor, and that possibly the inner ring could be removed without reducing performance, has possibilities which ought to be pursued. It may well be that the introduction of high top-pressure would permit the use of designs of dry-cleaning systems which, coupled to a disintegrator of the design suggested by Mr. Jennings, would contribute to reducing the cost of cleaning and at the same time maintain a high standard of performance.

Mr. **P. G. W. Hawksley** (British Coal Utilisation Research Association): Mr. Stringer quotes Pettyjohn and Christiansen's empirical correction to Stokes' law for deviations from a spherical shape. If it is assumed that the viscous drag is proportional to the surface area of a particle, spherical or not, then the correction factor K used by Pettyjohn and Christiansen should be proportional to ψ^{-1}, where ψ is the sphericity. In fact, an analysis of their original data supports this simpler semi-theoretical relation. (The analysis is complicated by the existence also of a wall effect.) The point is rather an academic one, as the measurement of the particle shape itself is a very difficult problem, particularly for heterogeneous blast-furnace dust.

Mr. Jennings has gone very fully into the aerodynamics of gas cleaning; it would have been valuable if he had extended his treatment of the collection of particles by moving water droplets also to the collection of particles by stationary fibres in a filter. It seems probable that the efficiency of filter could be raised and the pressure drop reduced if there were more control on fibre size rather than on fibre spacing. Fine fibres, rather than close spacing, seems to be the important feature; in fact it is said that the microscopic hairs projecting from natural fibres do the bulk of the collecting in a filter.

Mr. Jennings considers that aerodynamic processes are the main separating agencies in gas-cleaning plant, but it seems improbable that this can be so with very fine particles of a few microns. The inertial and fluid drag forces are then so small that accidental disturbances, from convection effects or from irregularities in the fluid flow pattern, must seriously upset an aerodynamic separation. Agglomeration of fines to larger sizes will probably occur, especially as the local dust concentration in the separating regions is likely to be relatively high.

If this is the case, improvements to secure good aerodynamic separation might result in a decrease in overall efficiency, since the conditions for good separation are opposed to those for agglomeration. Another consequence is that care is needed in comparing the size analysis of dust entering and leaving a cleaner; for example, a high efficiency of cleaning in the finer sizes compared with larger sizes might be due to agglomeration of the fines, with an increase in the quantities of larger sizes leaving the cleaner.

This also affects some of the remarks in the Appendix on the sampling and sizing of the dust. The author has omitted one of the most important requirements: that in taking and sizing a sample there must be no change in the size of the dust. This rules out all methods in which a sample is collected before sizing, for example on a filter, since fine particles, if brought into contact, stick together with forces not far removed in magnitude from the bonding forces of the dust particles themselves. It is then impossible to redisperse to the original state of agglomeration, and thus it is necessary to employ an aerodynamic sizing device operating on the airborne dust. The author mentions the Conifuge, which would be satisfactory from this point of view, but in its present form this instrument does not give weighable fractions, and only a number size distribution can be obtained. The conversion to a mass distribution requires a knowledge of size, shape, and density variations, and would hardly be possible for blast-furnace gas. One other point on sampling is that there may be serious losses and changes in size between the sampling point in the gas stream and the sizing device. Ideally, the sizing

device should be inserted in the blast-furnace main at the sampling point ; this may not be impossible.

Mr. **A. Puttick** (Whessoe, Ltd.) : The efficiency of the pre-cooler can be of very great importance, because the dust content of the gas leaving the pre-cooler can have a very marked influence on the operation of any subsequent plant unit. For instance, in the case of a wet continuously flushed precipitator following a pre-cooler, we found that, where the dust content at the inlet to the precipitator is low, the electrical stability is very good and high gas velocities can be used. On the other hand, where the dust burden is high there is a much greater tendency towards electrical instability, and the gas velocity has to be lowered to obtain stable running. As the size of the plant depends on the gas velocity which can be used in that plant, this question obviously has a very important bearing on the cost of an electrical precipitator. It therefore seems probable that any investigation into the improvement of pre-cleaning in a pre-cooler would pay very high dividends.

Mr. Jennings quotes a figure of 67% for the cleaning efficiency of the boosting fan after the electrical precipitation plant, which he describes as plant *B*. At first sight this figure, for an ordinary boosting fan dealing with a gas already cleaned to a very high degree, is somewhat surprising ; it may be of interest to mention that we have experienced a similar effect in a continuously flushed wet precipitator followed by a boosting fan. This fan has been dealing with a gas which has already been cleaned down to less than 0·02 g./cu. m. in the precipitator ; but in spite of this it does further cleaning, to the extent of approximately 50% efficiency, on that highly cleaned gas.

Mr. **J. H. Flux** (The United Steel Companies, Ltd.) : To calculate accurately all the forces acting on dust particles carried by gases passing through any form of dust extractor is extremely difficult and painstaking, and the work has only just been commenced when the calculations shown by Mr. Stringer have been completed. It would be interesting if, at some future date, Mr. Stringer were to give further consideration to the applications of the nomograms which he has devised. For example, in describing the cyclone, Mr. Jennings assumes that the terminal velocity of the particles is obtained almost instantaneously ; it would be of value if Mr. Stringer had illustrated the motions over the range of velocity from zero to the terminal velocity, with examples from standard plants.

On p. 304, following equation (44), Mr. Stringer states that in any particular case the density and the kinematic viscosity of the gas are known, which is, of course, correct. He also says that the acceleration of the particles is known, yet at the same time he does not know the density and shape factor. How can the two statements be reconciled ? Moreover, he says that, independently of equation (45), G (the ratio of a dimensionless factor and a shape factor) is a function of the terminal Reynolds number. Perhaps he would indicate from whence he gets that relationship.

Turning to the paper by Mr. Jennings, one would have thought it possible, in a review of plant performance, to have extended the information given in Tables I, II, and III, and to have given some assessment of the relative merits of the various methods of gas cleaning. Supersonic agglomeration of particles has not been fully discussed, but it is believed that the efficiency of electrostatic precipitation can be improved by such methods. Has Mr. Jennings any information on that subject ? Also, is there any information on the way in which the efficiency of an electrostatic precipitator is affected when dealing with fine iron particles which are conducting and may be magnetic ; and what is the effect of temperature on the efficiency ?

On the theory of cyclones, it appears that Mr. Jennings has tried to condense the mathematical background a little too much. He has omitted to note that the velocity of the gas stream passing through the cyclone at any one point can be divided into three components, tangential, vertical, and radial, and not just tangential and radial, as suggested in the paper. Also, which method is used to obtain the terminal velocity ? Support is given to the present use of banks of small-diameter cyclones ; other workers have suggested that the practical optimum diameter is of the order of 6 in. Has he any comments, and could he give an indication of the methods by which effective, even gas distribution at the inlet to the individual cyclones can be obtained ?

Mr. Jennings says that with bag filters the construction of the cleaners is not suitable for high ingoing gas pressure, and that the present forms of bag filter are not suitable for furnaces with a high top-pressure. Surely this does not present any insuperable problem to manufacturers : are any developments on these lines contemplated ? It appears that the Venturi gas scrubber would be the most effective for high top-pressure, because it would not be necessary to boost the gas to overcome the resistance of the Venturi. Whilst being used to clean waste gases from open-hearth furnaces during oxygen injection into the bath, erosion and wear of the metal parts appears to have been very severe. Can Mr. Jennings give us any information on this ?

On the question of washing plants, is it practicable to use wetting agents, and would the efficiency of a washer be improved by their use ?

CORRESPONDENCE

Mr. **F. L. Robson** (James Howden and Co. (Land), Ltd.) wrote : The theory of particle movement, whilst of extreme importance in studying the design of gas-cleaning apparatus, does not alone give a complete picture of the mechanism of aerodynamic dust removal by what are commonly termed mechanical collectors. The detailed flow system in cyclones is not even now fully known, particularly with regard to the complicated mechanism of secondary flows and re-entrainment, although some work has been done successfully in this direction. For this reason it is practically impossible to design a mechanical collector to give a 100% cut of any particular size. The only way to ensure such efficient removal would be to design for a smaller particle size cut, in which case a further possibility becomes apparent, namely, that of the ejection of a small number of larger particles, owing to tangential collision with the walls of the collector and consequent bouncing into the region of powerful inward drift towards the centre of the collector.

There is a tendency today to quote the efficiencies of high-efficiency multicellular dust collectors in terms of fractional efficiencies, *i.e.*, the efficiency with regard to particle size range. Whilst this is probably the best way of forecasting the efficiency which might be expected from a particular collector on a dust of known analysis, it must be realized that it would be almost impossible to prove in practice whether or not a collector was actually achieving such fractional efficiencies, because of the difficulty of arriving at the original particle-size analysis of certain dusts after they have been collected, owing to their tendency to form bonded agglomerates. This occurs to a greater extent in the ranges of finer particle size.

The fractional efficiencies of these collectors are usually determined experimentally using specially selected dusts, which are chosen for their resistance to breakdown and

degradation and their low tendency to form agglomerates.

If very high efficiencies are required, it is possible to achieve them by using high-efficiency multicellular collectors in tandem. To observe the effect of this, it is necessary only to consider the fractional efficiency of such a collector on any particular dust, and to note its total calculated efficiency. The second collector in series would have a somewhat lower efficiency, because of its extremely low dust concentration at inlet. The overall efficiency of this second collector would also be further reduced because most of the larger particles, in which range the collecting efficiency is high, would have been removed by the first collector.

In these circumstances one might generally expect that, with a certain dust on which a multicell collector would give, say, a total efficiency of 90%, the second collector of the same type would perhaps give an efficiency of the order of 60%. Thus the overall efficiency would be of the order of 96%—this with a dust generally of the type containing approximately 80% below 40 microns.

Experiments have shown that, with the exception of the disintegrator type of plant, other washing or spray-tower systems offer very little improvement in efficiency over the present-day type of small cell multicellular collectors, and certainly would not appear to warrant their very high running cost. In addition, the modern multicellular collectors will work at reasonably high temperatures and have, in fact, worked up to temperatures of 500° C. quite successfully.

The author refers to the difficulty of obtaining satisfactory gas flow to each of the cells of a multicyclone system. This problem would appear to be best solved in the manner of the current multicellular small cell collectors. Advantage is taken of the fact that the cells can be closely banked together and incorporated in a single dust-collection hopper. This allows the use of inlet and outlet connections, which can be so designed as virtually to form plenum chambers.

From the point of view of capital cost, low maintenance, and low operating costs, a scheme worth considering for the cleaning of blast-furnace gas would be to employ a modern high-efficiency multicellular collector, followed by either a disintegrator or a precipitator.

Reference has been made already to the difficulty of assessing particle size efficiency on operating plants because of bonding and agglomeration, and I can confirm Mr. Hawksley's remarks in that respect. Liquid sedimentation seems to offer certain advantages in this field, as it offers better opportunities for dispersion of the particles. But if powerful bonding has taken place in the sampling apparatus—and I have actually encountered some cases where this has been so—then it becomes impossible to arrive at a satisfactory determination of the original particle size : even microscopic examination will not give satisfactory results. The answer would appear to rest in the future development of a sampling instrument which in itself incorporates one or two particle size cuts and therefore gives a sample which is already primarily analysed into its main component particle sizes, probably sufficiently so, in fact, to enable the performance of the plant to be reasonably assessed.

AUTHORS' REPLIES

Mr. **R. F. Jennings** said in reply : Dr. Jackson may be interested to know that a slotted cone type of filter called the Musgrove, which I think is what he had in mind, has been proposed for experimental trial at a small blast-furnace plant.

The tables of size analysis of dust given in the paper are taken from previous analysis done on behalf of a steel company, and I used them because they were the only figures of that sort which were available. As Dr. Jackson will be aware, that kind of size analysis requires a very specialized technique, which was not available to us.

The efficiency of electrostatic filters with very small dust particles is interesting, because electrostatic filters apparently are not necessarily as efficient for the finest sizes of dust as for the slightly larger particles. It is difficult to say exactly why, but it may be influenced by the fact that the total charge on very fine particles—less than 1 micron in diameter—is generally considered to be proportional to the diameter, and not to the square of the diameter, whereas the drag on such particles is a function of the square of the diameter. It may be, therefore, that the resultant increase in the drag on very fine particles in a given electric field is sufficient to decrease the efficiency of dust separation.

I agree that the sampling of gas from a main is a most difficult problem, but it should be remembered that the sampling of blast-furnace gas at various points in the system is simpler than in a power station flue, where a very wide range of particles is present in the gas stream. A sample from a cleaned blast-furnace gas main will contain particles which are all substantially fine, and therefore the chances of obtaining an incorrect sample are fewer, and there is a better chance of obtaining a reasonably representative sample of the dust content.

Mr. Hawksley is quite right in emphasizing the idea of a fundamental approach to the design of fibre filters, although this is not easy to achieve in practice. I believe that some work has been done on it, but that it has not yet been published.

On the question of different forces applied to cleaning, I agree that those of agglomeration are opposed to separation, but agglomeration can only be used for removing the particles of dust from a gas stream if the concentration is high. For example, ultrasonic separation, which has been tried in the U.S.A., appears to work only in a dust concentration greater than 1 grain/cu. ft. Below this concentration, aggregation does not take place. The same may be true of diffusion.

It must be remembered that there is a vast volume of gas passing through a cleaning plant at a blast-furnace, and if the space occupied by the plant is to be kept reasonably small the gas velocities are bound to be high, so that the time taken by the gas to pass through each section of the plant is very short. Therefore, the forces for efficient and effective separation of dust must be highly concentrated. That, I think, is the reason why forces such as diffusion cannot easily be employed.

I agree with Mr. Hawksley on the difficulties of dust sampling. The ideal to aim at is to sample and analyse the dust before it has had time to become agglomerated in the sampling equipment. This requires that the dust should be analysed for size in its air-borne state, which is very difficult to achieve in practice.

Mr. Flux mentioned the optimum size of cyclone : I agree that it is difficult to maintain equal efficiency throughout a large bank of cyclones with a common entry, and it was for that reason I suggested that a relatively small number of cyclones, say half a dozen, might be used. Under those conditions, individual control could be given to the gas stream passing through each cyclone. I understand that the Venturi scrubber system has now been given further trials in the U.S.A., on blast-furnace gas as well as on open-hearth furnace gases. These tests have been reported elsewhere.*

* Symposium on Atmospheric Contamination and Purification, *Industrial and Engineering Chemistry*, 1949, vol. 41, pp. 2383–2493.

The use of a wetting agent to improve the efficiency of wet cleaning would undoubtedly have a favourable influence ; but the minimum effective concentration of a wetting agent is about 1 part in 1000, and unless the cleaning water can be recirculated without loss, the cost of the wetting agent may well be greater than the pumping and circulation cost of untreated water.

Dispute over the performance of multicyclone systems will continue until more experimental data from works trials are available. In this connection, Mr. Robson may be interested to know that B.I.S.R.A. are shortly to commence works trials of a multicyclone collector followed by a novel design of water spray cleaner based on the principles proposed in the paper.

Mr. **J. Stringer** wrote in reply : In answer to Mr. Flux's detailed comments on equation (44), f is not the particle acceleration but the strength of the ' field of force ' in which the particle is moving. This must be assumed to be known, or to be readily calculable. Equation (45) is simply a rearrangement of the definition of G, and the other relationship referred to is given in Fig. 3 of my paper.

Joint Discussion on the Papers—

PROPOSALS FOR THE MODIFICATION OF A BLAST-FURNACE TOP TO GIVE CONTROLLED BURDEN DISTRIBUTION*

By E. L. Diamond

and—

A NEW BLAST-FURNACE STOCK-ROD GAS SEAL†

By E. J. Walklate

Mr. **E. L. Diamond** (British Standards Institution, formerly British Iron and Steel Research Association) presented his paper.

Mr. **F. C. Doherty** (Stewarts and Lloyds, Ltd.), who introduced the paper by Mr. Walklate, said : Before dealing with the type of seal which is the subject of this paper, it may be of interest to trace the history of the experiments undertaken at Corby to find the best type of stock-rod seal.

Leakage of gas from blast-furnace tops can be traced to three major causes : (i) leakage between the rotary distributor hopper and the fixed casing over the large bell hopper ; (ii) leakage through the hollow small bell rod at the point where the large bell rod emerges ; and (iii) leakage through the stock-rod sleeve where the rod emerges. Loss of gas from (i), with a badly fitting large bell and high gas pressure, may be serious because of the large area involved ; but in neither of the first two cases are the normal conditions so onerous as in (iii), where the gas seal is continuously exposed to the full pressure in the furnace top, coupled with a momentary great increase of pressure when the burden slips or rolls.

All four Corby blast-furnaces were equipped originally with a metal-to-metal seal for the rotary distributor hopper, which depended for its effectiveness on the dead weight of the rotary hopper, as shown in Fig. A (*a*). The seals for the large bell and stock rods were merely close-fitting steel collars embracing these rods at their points of exit. With hard driving of the furnaces, coupled with a gas pressure of 60 in. W.G., none of these seals proved effective, and at one time loss of gas from all causes, including week-end loss, amounted to approximately 30% of the make. It was therefore imperative that the causes of leakage should be thoroughly investigated.

As a result of the work done at Corby, the overall gas loss has been reduced to 10–15% of the make, and when No. 2 furnace has been modernized the loss is expected to be still further reduced, to about 8%. Part of the credit for this must be attributed to a lowering of the furnace-top gas pressure to about 40 in. W.G., consequent on extensions to the gas-cleaning plant.

The installation of a new type of distributor, embodying a stuffing-box containing two rings of hydraulic lip packing under pressure from a Tecalemit high-pressure grease lubricating system, has almost completely stopped gas leakage between the rotary hopper and the fixed gas-seal casing. The arrangement of this seal is shown in Fig. A (*b*). Loss of gas from the top of the small bell rod also has been reduced to very small proportions by the provision of a special type of split plate seal, as shown in Fig. B.

The third cause of loss, where the stock rod emerges from the furnace, has proved much more difficult to overcome. Over a period of years, however, a number of different types of seal have been tried out, and a much improved efficiency and length of life obtained. Figure C (*a*) shows the first type introduced. This consisted of a mild-steel block in halves, with a spherical seating which rested on the stock-rod sleeve. A total clearance of $\frac{1}{16}$ in. over the rod diameter was allowed. This idea, however, was not very successful ; dust very soon filled up the space between rod and seal and prevented free movement of the rod. Increasing the clearance naturally caused more loss of gas, and also resulted in the block being lifted right off its seat when excessive gas pressure developed owing to slipping of the furnace burden.

Figure C (*b*) shows the next experiment. In this case a thick rubber ring clamped between two mild-steel plates was fastened to the stock-rod sleeve. The original total clearance between rubber ring and rod was $\frac{1}{16}$ in., and between steel plates and rod was $\frac{1}{2}$ in. Float of rod was intended to be taken up by compression of the rubber ring. This type proved more successful than the first, but the ring hardened in service owing to sulphur in the gas, and was rapidly eroded.

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* *Journal of The Iron and Steel Institute*, 1950, vol. 164, Feb., pp. 173–181.

† *Ibid.*, 1949, vol. 163, Dec. p. 432.

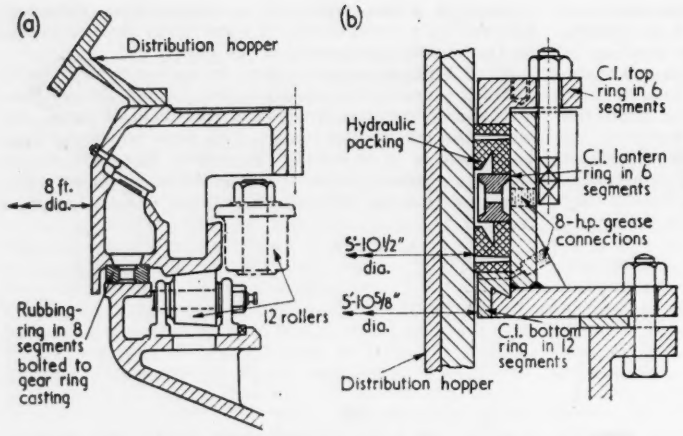


Fig. A—Types of seal for distributor hopper: (*a*) metal-to-metal seal as originally used; (*b*) installation of new type of distributor, showing hydraulic packing between rotary hopper and fixed gas-seal casing

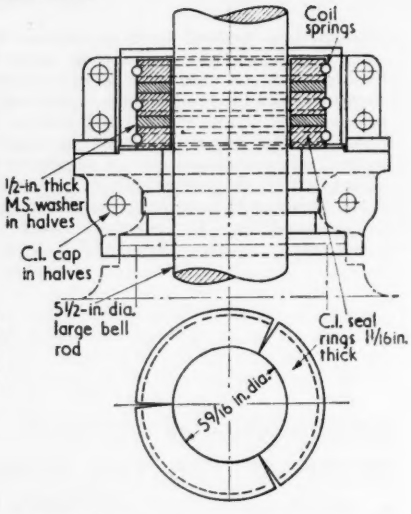


Fig. B—Split-plate seal, as modified for use with small bell rod cross head

The type shown in Fig. C (*c*) was then introduced. This proved to be a big improvement on the previous types, and in a modified form has been used for the small bell rod cross-head seal as indicated in Fig. B. The split plates were first made in carbon ; this provided a satisfactory seal but wore away quickly, the average life being three weeks. Brass was tried, and later cast iron, which made a good seal but tended to become clogged with dust fairly quickly. However, this type might still have been in use but for an idea, suggested by one of our blast-furnace fitters, which provides a very good gas seal with the minimum of maintenance, and from which our present design, described in Mr. Walklate's paper, has resulted.

An important addition to the seal which is not shown in the diagram has been the insertion of a hollow distance-piece, tapped for two ½-in. steam connections, between the top of the stock-rod sleeve and the underside of the outer casing. The hoist operator admits steam at 80 lb./sq. in. pressure to this point whenever the stock rod shows signs of sticking. The steam clears any accumulation of dust between the stock rod and the top of the sleeve. Since steam condensing on the stock rod tends to further the accumulation of dust, it must be used in moderation, and the hoist operator has strict instructions to use it to the least possible extent.

The method of repacking this seal is to remove the cover bolts and slide the top scraper ring, covers, and neck ring up the test rod, making the packed inner sleeve accessible. The used packing material is removed by a special tool, and a fresh supply of steel wool, previously soaked in ordinary soft grease, is pulled out into the form of a rope, wound round the test rod and packed down into the sleeve with a hammer shaft. The whole operation is accomplished by a fitter and his mate in 30–45 min. Occasionally, owing to furnace conditions, dust becomes so tightly packed in the stock-rod sleeve that steam pressure is unable to move it. In these circumstances the rod has to be removed for cleaning and repacking the gland, the time taken being about one hour.

The interval between each repacking of the gland usually varies from six weeks to three months, depending on furnace conditions, but on our No. 4 furnace, blown-in last October, the gland has not yet required repacking. This work is always done when a furnace is off blast

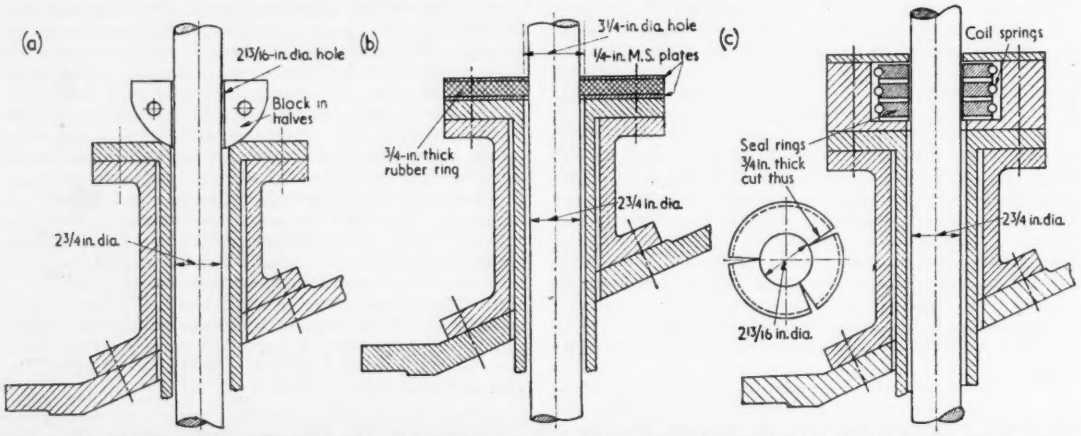


Fig. C—Types of seal to prevent leakage through stock-rod sleeve: (*a*) mild-steel block in halves, with spherical seating; (*b*) thick rubber ring clamped between two mild-steel plates; (*c*) split-plate seal

for another job. We hope, however, to improve the design so that the gland can be repacked at any time, while the furnace is on blast. Figure D shows one step in this direction. The inner sleeve and bottom neck ring are shown in two pieces, held together by removable rings at top and bottom. This will allow the inner sleeve to be split and replaced by a new one, thus saving the time necessary to clean the old packing out. Figure D also shows the steam pocket already incorporated in the present design.

In our opinion, one of the causes of eventual failure of the seal is pitting of the test-rod surface. The rods are made of bright mild-steel bar, and the pitting is caused not only by abrasion due to flue dust but also by corrosion resulting from the high sulphur content of the Corby iron ore. We have seriously considered making these rods of an alloy steel resistant to these effects.

In the Corby furnaces the test rod passes through the large bell hopper, and, to prevent leakage of gas into this hopper, a gland is provided at the point of entry of the 4-ft. long test-rod sleeve into the hopper. The gland consists of a few turns of asbestos cord wound round the sleeve and fitting into a 2-in. deep recess in the hopper casting. The cord is held in place by means of a loose cap sliding on the sleeve.

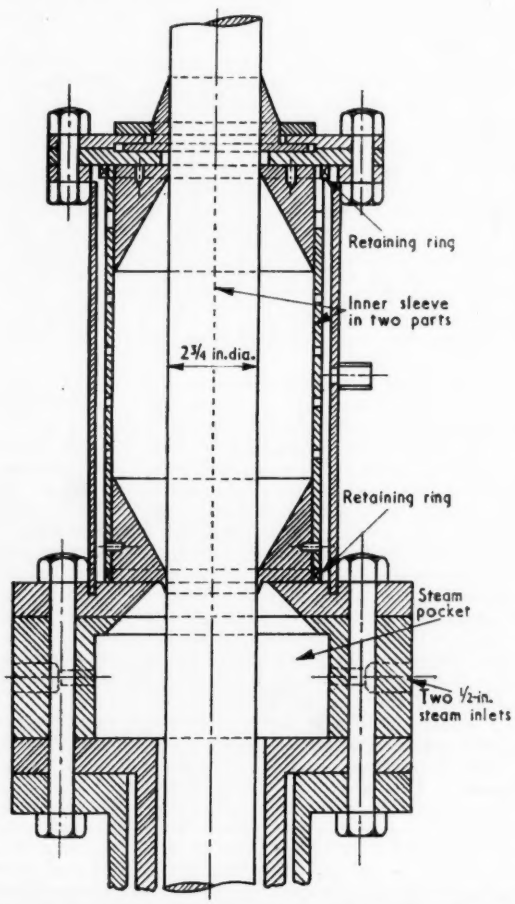


Fig. D—Suggested improvement on present design of seal, incorporating split inner sleeve

Mr. **I. S. Scott-Maxwell** (British Iron and Steel Federation) : I find it difficult, when considering these designs, to dissociate the top-charging mechanism from the result in the furnace down below. The present designs of top-charging gear are, from an engineering point of view, extremely good, but ironmakers have realized for many years that the results produced inside the furnace are by no means perfect. The difficulties arise primarily from the segregation of material which occurs at the stockline due to differences in the size and density, and which persists for a long way down the shaft.

In the double bell and hopper system with which we are all familiar, it may be said that, in general terms, relatively large material is deposited in the centre of the furnace and also at the walls, in varying proportions, whilst the fine material segregates under the lip of the large bell. This result gives rise to preferential gas flow, which means that the total effective volume of the furnace is not being fully utilized for preheating and reduction of the ore.

Another aspect is that as furnaces have been built for larger and larger outputs the ineffective use of furnace volume has tended to increase stack height in relation to hearth diameter. Again, the uneven distribution which we experience with present methods also gives rise to different rates of descent for the materials moving down the furnace. Under extreme conditions this will cause violent slipping of the charge, high flue-dust production, and uneven hearth temperatures, also irregular iron quality ; but some of these effects are probably present even during normal operation.

It is therefore very important that, if at all possible, the present methods of distribution should be improved. Such an improvement would tend to keep stack heights down, owing to a greater utilization of the effective furnace volume, and would therefore lower the capital cost of any installation. More effective use of the furnace volume would increase the output of the furnace for any given size, and would thus lower production costs.

The designs submitted in the paper are, as the author has explained, the logical outcome of a long series of investigations into these problems, chiefly in the laboratory, coupled with some investigations on full-size furnaces. Two alternatives are submitted whereby the fines and lumps may be distributed more evenly across the stockline area. This will have the effect of eliminating the preferential gas flow and all its attendant troubles. These proposals, therefore, go to the root of the matter, and when they have been developed into a practical operating design I suggest that many of the present furnace operating troubles will disappear.

I sincerely hope that this idea will be pursued with some interest, and will not be swamped by the increasing popularity of American 'high top-pressure,' which in some respects achieves the same kind of result. There is, however, another aspect of the matter which must be kept in mind, particularly in relation to British home ore practice, and that is ore preparation. Crushing, screening, and sintering of ore are carried out mainly to improve the quality of the iron-bearing material. As a result, by easing the load on the furnace, increased output and lower fuel costs are obtained. However, the effect of ore preparation on distribution is to minimize the amount of segregation, and progress in this direction must therefore be considered. It may be that ore sizing, sintering, and charging the furnace in sized layers, is the most practical and economic solution for the most efficient use of British ores, which are fairly consistent in physical characteri ics. The problems arising in those plants using a variety of imported ore are a very different matter. Nevertheless, a combination of ore

preparation and controlled distribution might produce phenomenal results.

The two designs given in the paper are the moving frustum and the fixed frustum. To clarify the position, I have looked at each design under three separate aspects. These are : (i) the operating gear outside the furnace, (ii) the gear inside the furnace, and (iii) the effect of each system on the distribution. Taking them in this order, the first design has very simple external equipment. It would not be very difficult to operate or to maintain ; in fact, the only additional gear over the normal McKee top is the three rods supporting the frustum and coupled through chain links to one operating rope. The main disadvantages of the first proposal are in regard to the inside apparatus. The design as given in the paper seems to require a larger throat diameter than the furnace to which it is fitted, and, as the author has explained, the large bell hopper is far too small. I imagine that the effective volume of this hopper is even smaller than the small bell hopper, so that each of the bells would have to be operated after every skip. Finally there is the real difficulty of maintaining correct clearance on the moving frustum while permitting constant operation without any jamming. With regard to distribution, this design gives complete control and flexibility. In fact, as pointed out in Fig. 12*a* of the Appendix, one dumping position, No. 5, is not really necessary. In view of the great variety of imported materials which we have to use in this country, I think that at least four dumping positions are necessary. In future we must be prepared to use many different ores, whether we like it or not.

In the second design, the outside mechanism seems to be very complicated. There are many small moving parts—cams, guide rollers, spring-loaded levers, steam cylinders, etc.—all of which would not receive the necessary attention, and would be difficult to maintain. They are at a considerable height above the ground, exposed to the weather, to considerable ore dust, and to coke dust. It seems that in an effort to simplify the equipment inside the furnace the gear outside the furnace has been made too complex for normal working conditions. The inside part is certainly very simple, and no problem should arise in connection with the fixed frustum. The large bell hopper is of ample capacity. and the design can be made to suit existing furnaces. The resulting distribution, however, is not so good. There is not full control as with the first design. The design of the fixed frustum, as the author points out, has to be made to suit the materials being used. He says that the position of dump No. 3 can be suitably altered by designing the fixed frustum accordingly. The difficulty here is that nobody using imported ore can really say in advance what kind of material is going to be used. It looks, therefore, as if the problem of designing the fixed frustum might be something of a hit-and-miss business.

I conclude therefore, in a general way, that the first design scores two plus marks out of a possible three, and one minus ; and that the second design has the reverse, namely two minus marks and one plus. It is unfortunate, of course, that the designers have not been able to get all the advantages in the one design and leave out all the disadvantages.

However, I think that the overall effects of both designs, and particularly the first one, have been somewhat distorted by trying to adapt them to existing furnaces. This may have been deliberate policy, but the disadvantages of the first design, namely the small hopper for the large bell, the possible jamming of the moving frustum, and so on, could be overcome if the design were made in conjunction with a furnace, the whole being made into one integrated unit.

Perhaps this is too bold a step, but unless this is done the inherent advantages—and they are quite great advantages—in the proposals before us may be lost and discarded as impracticable. With controlled distribution it will be possible to design a furnace with a lower height of stack for the same output, or even a greater output, because more effective use will be made of the available furnace volume. If we retain the normal stack batter, the furnace will have a much wider throat. This will give ample freedom to fit the fully controlled mechanism of the first design. For these reasons I think that the paper would have carried a great deal more weight if the author had been able to include a design for a new furnace with a moving frustum, as well as the designs shown. I find it very difficult to isolate the top-charging mechanism, which is essentially an engineering problem, from the metallurgical portion of the furnace which is down below.

In spite of the difficulties, I hope that the matter will not be dropped, but that some interest will be shown by the industry. The next step should be the construction of a full-scale mock-up, erected on or near ground level, so that all the mechanical working details and the electrical interlocking sequences can be worked out. My own opinion is that the moving frustum design should be adopted for trial, although I believe that this is contrary to recently expressed opinions from some of the experts in the industry. I think that, from an operational point of view, the first design has advantages which outweigh all the disadvantages of both designs.

Have these designs been considered in relation to a new furnace and planned as an integrated unit ? In connection with the moving frustum, does this design actually require a wide throat diameter—this is not quite clear—or could part of the difficulties be overcome by making the frustum steeper and of smaller diameter, and dropping the whole equipment deeper into the furnace ? Finally, in regard to the fixed frustum, is it possible for the author to indicate the extent to which the design of the frustum affects the No. 3 dump position in relation, say, to wet, sticky material like Northants ore, or to a free-running material like Newfoundland ore ?

Dr. **R. Wild** (Imperial College of Science and Technology) : Mr. Diamond has, quite rightly, not sought to minimize the difficulties involved in fitting and operating these charging mechanisms, but there is one point which I should like to clear up with regard to the moving frustum head-gear referred to in the Appendix to his paper, where it is mentioned that a considerable simplification of the working may be obtained by using a four-operational cycle rather than a five. By carrying out this modified cycle in the manner indicated in the Appendix, the need to retain material between the frustum and the outer hopper is obviated and so the clearance between them can be increased considerably, thus minimizing the possibility of the frustum jamming. That, I think, does at least remove one of the difficulties inherent in this type of mechanism.

I would also like to say a little about some further experimental tests, which were made with the $\frac{1}{2}\frac{1}{4}$-scale model shown here, and were carried out at Imperial College. The tests initially carried out were of necessity limited in scope, and therefore did not prove conclusively the flexibility of the head-gear. Thus, although they demonstrated that either type of head-gear was able to produce a uniform distribution of lumps and fines across the stack, no experimental evidence was available to show that various alternative forms of distribution could also be obtained.

Further work has since been carried out with the moving frustum head-gear, using the simplified four-operational cycle which I have already mentioned; the results, which prove that a wide range of segregation patterns may be obtained, are shown in Fig. E. The table at the top shows the various target distributions that were set. The first was a simple, uniform distribution across the stack. The second was uniform in the centre, with an excess of lumps at the walls and an excess of fines intermediately. The third was the converse of this, with uniform distribution in the centre but an excess of lumps in the intermediate position and an excess of fines at the walls. The fourth was a large excess of lumps at the centre balanced by a small excess of fines elsewhere. In the lower diagram the percentage of lumps and fines is plotted against the distance from the centre of the furnace, and it will be seen that those targets have been attained.

Although these additional experiments were carried out using the moving frustum head-gear, there is little reason to doubt that a similar result could be obtained using the fixed frustum head-gear.

Mr. **Doherty**: As mentioned by Mr. Diamond, the Corby drawing office took some part in the moving frustum design. Our opinion was that the design was very interesting and might show some good results, provided somebody could be found with the courage to try it out on a full-size furnace. A blast-furnace, unlike many other items of the plant, cannot be shut down to repair or to remove an experimental unit that has proved a failure, except at enormous expense.

Progress in blast-furnace development must, of course, go on, but it would seem that the sizing of ore, sinter, and coke, which is a feature of modern practice, will to a large extent overcome the problem of stockline segregation and make the provision of more complicated charging apparatus less necessary.

Both the designs described in this paper, as adapted to an existing furnace, would require the lowest bell position to be 1–2 ft. lower than normal, with a consequent slight reduction in volume of material in the stack. Opening the large bell for every skip load would mean some loss of operational time, as would also the operation of the somewhat complicated mechanism for lowering the large bell to positions 2 and 3 in the second design.

	CENTRE		INTERMEDIATE		WALL REGION	
	Lumps	Fines	Lumps	Fines	Lumps	Fines
A	Uniform		Uniform		Uniform	
B	Uniform		− −	+ +	++	− −
C	Uniform		+ +	− −	−−	+ +
D	+ +	− −	−	+	−	+

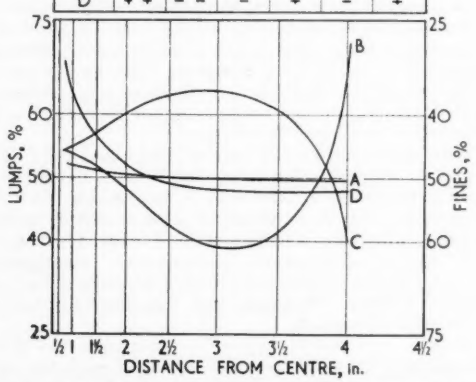


Fig. E—Distribution of lumps and fines across stack. The Table shows the target distributions

Both of these schemes might operate satisfactorily with a burden consisting of ore, coke, limestone, etc., and sinter, but there would be a tendency for jamming to occur if awkward-shaped scrap was included in the charge.

The author says that the mechanism for operating the fixed frustum design could be simplified if the source of movement were transferred to the furnace top, which present practice does not favour. For several years, 21-in. dia. air cylinders operating at 100 lb./sq. in. pressure were used on the tops of the Corby furnaces for actuating large bell-depressing mechanisms, required on account of the high gas pressure. These cylinders and the lever arrangements gave no trouble and proved quite satisfactory.

The complicated mechanism required for the second scheme is a factor which is very much against it, but it is stated in the paper that springs would be required to move the dashpot pistons back to their original position. I suggest that if these dashpots were to operate against a constant pressure produced by oil, or possibly water, through an air hydraulic accumulator, this difficulty could very largely be overcome.

Mr. **A. Bridge** (Appleby-Frodingham Steel Co.): I think Mr. Scott-Maxwell was quite justified in raising the point about the limitations of both the schemes. The scheme for the moving frustum was devised with the object of trying to fit it to an existing furnace top; given a free hand, the objections with regard to lowering the second small bell (*i.e.*, the top of the original big bell) for every skip could be overcome.

I do not agree with the statement that the fixed frustum scheme is simpler than the moving frustum scheme, because it definitely is *not*. The thought of those dashpots, holding cylinders, trips, and cams, etc., on the top of a blast-furnace is a nightmare to me as a maintenance engineer.

The difficulties of jamming have been mentioned but, again, I think they could be overcome. The three hanging rods in the moving-frustum scheme could be sufficiently guided to give rigidity, and the only additional mechanism exposed on the furnace top is the four sprocket wheels with their operating chains and ropes. The remainder of the operating gear is fairly simple, and could be located in the hoist engine house or some other suitable position remote from the furnace top.

I also agree with Mr. Scott-Maxwell that a full-scale mock-up should be tried out at floor level in the first instance, to study the mechanical operation and rectify any snags that may become evident.

Dr. **H. L. Saunders** (Imperial College of Science and Technology): In two or three years' time we will be inundated with fines in this country, and we shall have to smelt these fines if we are to keep up our output. To do this some means must be found to make the fines stay in the furnace. Flue dust may amount to 150–250 lb. per ton of metal made, and this is serious. Why is this flue-dust loss so high? There is, I think, only one answer, and that is the localized channelling due to maldistribution; I do not see any other answer which can logically be given. If the high-velocity gas streams in the furnace were averaged out over the whole area of the stack, then these local effects would become quite insignificant. Moreover, because of the better gas/solid distribution and the increased overall time of contact, one would expect the coke rate to be reduced This is in fact the basis of radial control, or 'radcon,' as it is now called.

It is evident that a great deal of thought and work have been put into the designing of these modified charging systems to secure this improvement in furnace operation. We have received offers of assistance to

try out the scheme at ground level, and we very much appreciate them, but no one has yet volunteered to test the installation *in situ*.

Some remarks have been made about our competitors—burden preparation and high top-pressure. Burden-preparation plant involves a large capital expenditure, but admittedly it can deal with many thousands of tons of material. However, not every works can have its own plant, and if distribution from a central point is contemplated there comes a stage when freight charges become serious. There are two questions which I would ask in connection with burden preparation. Is it the initial 25% or final 25% of preparation which really counts in reducing the coke rate, and thereby the cost of the iron? Secondly, is burden preparation alone entirely sufficient? Should we not consider coke bedding also, to level out not only size factors but also the wide differences in the coke quality, particularly where certain plants are forced to use such a large number of different kinds of coke? Until this is done it will be necessary to keep a close watch on charging cycles, to ensure that the elimination of fines selectively when operating a normal cycle is not, in fact, placing good material into the furnace in the wrong place. This is just where 'radcon' would score—any material could be located at will.

I have mentioned high top-pressure, and I know that many people in this country are eagerly awaiting the outcome of the first pressure trials in this country. I would mention here, however, that this innovation was introduced in the U.S.A. on the basis of far more meagre experimental evidence than is available for radial control, which, apart from hundreds of photographs and experiments carried out in the laboratory, has at least been tested at a pilot stage. Moreover, the basic design of radial control could be adapted to any size of furnace, and could be suitably arranged according to whether the furnace was dealing with home or foreign ores, or even with mixtures. If one-tenth of the energy expended in the U.S.A. on the solution of the many problems associated with high top-pressure had been directed, in this country, towards 'radcon,' I think the conservatism and doubts about maintenance of alignment and the associated mechanical difficulties would have been overcome long ago. The control would be no more complicated, and the cost of the installation would at least be comparable, if not less.

One final consideration: why not process more of our fines directly inside the furnace, and so save on the continually mounting costs of sintering?

AUTHORS' REPLIES

Mr. **E. L. Diamond** said in reply: We were asked to prepare proposals, and we thought it would be better to propose two, rather than one. If those responsible are persuaded that the first proposal is practical and no more likely to cause trouble than the second, they would be well advised to adopt it, because it undoubtedly gives a greater measure of control. We thought that, at any rate in the first blast-furnace to work in this way, it would be better to have the parts which are likely to go wrong outside and accessible, rather than inside, where they might put the blast-furnace out of action for a very long time, and I think that this was the view of the Committee.

We confined ourselves to evolving designs applicable to existing furnaces, as it seemed extremely unlikely that anyone would be willing to build a new furnace of unorthodox design to operate on this system. It was a question of approaching the matter in a practical way. I agree that the first proposal suffers from trying to adapt it to an existing furnace, but on the other hand it was a matter of satisfaction that we were able at least to make proposals which would fit into the design of an existing furnace.

In regard to the control of distribution with the two proposals, I should like to point out that Fig. 12 in the Appendix was obtained in both cases by discharging single skip loads. If four or five skip loads are discharged in the model, as is possible with the fixed frustum and as would be the case in normal practice, the intermediate distribution is a big heap covering the whole of the range between the two. The more refined method of distribution with the moving frustum, as shown by the diagram, would therefore not necessarily be possible when dropping the normal quantities from the main hopper. Dr. Wild is, however, quite right about the possible alleviation of the problem of clearance at the bottom of the moving hopper, although there is still the difficulty at the top.

Mr. Doherty's experience with the operation of air cylinders at Corby suggests that the objections to having moving parts at the top are exaggerated. A hydraulic accumulator could be used instead of springs in the dashpots, but it might be difficult to find space for it.

I agree that these proposals will have to be pursued very much further, but it was not worth while doing so as long as we were dealing in generalities. The moment a particular blast-furnace is available for conversion, the matter can be taken very much further, because there will be precise data with which to work.

Mr. **E. J. Walklate** (Coppee Co. (G.B.) Ltd.) wrote in reply: As the designer responsible for the application of the moving-frustum scheme to an existing type of blast-furnace, it must be stated that from the outset the scheme, as applied, could only be regarded as a compromise, as the characteristics of existing furnaces do not allow the necessary scope for such a major alteration to be executed economically. The points of weakness are obvious, and have already been amply treated in the discussion.

It would appear that there is a good case for improved burden distribution, and if production experts can substantiate the considerable claims spoken of in the discussion, a scheme of controlled burden distribution would be worth while incorporating in a new design; this would enable the subject to be treated in a far wider aspect. Many changes could then be made to improve distribution, and one can visualize the outmoding of the conventional bell, and of other methods employed which by their design and disposition would give the desired theoretical effect, with more margin on the practical and maintenance side.

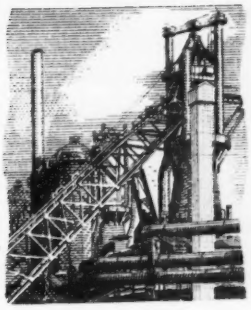
The description given by Mr. Doherty of the evolution of various forms of sealing at the tops of the Corby furnaces, including that of the stock-rod, was extremely interesting. It appears, however, that, as far as the stock-rod gas seal is concerned, as often as one difficulty was overcome another became apparent, and to some extent this position still exists.

With this in mind, the author abandoned the idea of a packed gland in the later stages, and developed a scheme for using a fluid seal in connection with the stock-rod. This is designed to give thorough sealing, together with easy cleaning with the furnace 'on' or 'off' blast, and minimum maintenance. Changing of the rod can be carried out without disturbing the seal, and the problem attendant upon the pitting of the rod is entirely eliminated.

Such a seal would appear to overcome the major difficulties previously encountered on gas seals for blast-furnaces.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Investigation of the Effects of Controlled Variables on Sinter Quality

Part I—DEVELOPMENT OF EXPERIMENTAL SINTER PLANT AND PRELIMINARY RESULTS USING NORTHANTS ORE

By E. W. Voice, B.Sc., A.Inst.P., C. Lang, B.Sc., and P. K. Gledhill, Ph.D.

SYNOPSIS

A sinter pan 2 ft. square was set up using suction from a production sinter plant, a separate fan being later erected to give controlled suction up to 32 in. W.G. Sinter was produced from weighed mixes, the sinter process was observed, and the sinter made was assessed for physical properties. Results showed agreement with previous data obtained on the full-scale sinter plant and, owing to the closer control and greater flexibility attainable with the small unit, quantitative results were achieved showing the effects of flue dust, returned fines, and coke on the sinter strength. Correlation was obtained between moisture content and suction on the speed of sintering, and observations were made of bed porosity and air flow before and during sintering. The effects of various fuels were also studied.

THE full-scale plant trials carried out on Messrs. Stewarts and Lloyds' No. 3 sinter plant at Corby,* showed that for a given ore the carbon content of the mix was of prime importance in controlling the quality of sinter produced. During these experiments plant conditions could not be sufficiently modified to provide a wide range of variables or to prevent fluctuations of carbon content. These fluctuations can easily mask the effect of the other variables being studied.

Earlier experiments had suggested that sinters comparable to those produced on the plant could be made on a small unit of only 1 sq. ft. grate area. With such a unit close control can be exercised over the raw-material composition, and instrument measurements can be made accurately and conveniently. Many operators considered that the size mentioned was too small, and it was therefore decided to try out a unit of 4 sq. ft. grate area with which it would still be possible to maintain adequate control. Messrs. Stewarts and Lloyds, Ltd., Corby, were also interested in experiments on such a machine, and offered to co-operate with the British Iron and Steel Research Association in the erection and use of a unit of these dimensions.

* D. W. Gillings, E. W. Voice, C. Lang, and P. K. Gledhill, *Journal of The Iron and Steel Institute*, 1951. vol. 167, Apr., pp. 400–439.

Many tests, both chemical and physical, can be applied in order to assess the quality of sinter. Most British operators stress that primary requirements of good sinter are freedom from dust and resistance to mechanical breakdown. Assessments of the experimental sinters were therefore concentrated on the physical strength.

DESCRIPTION OF SINTER UNIT AND EXPERIMENTAL PROCEDURE

The Plant Without Suction Control

The layout of the unit is shown in Fig. 1, and consists essentially of a 2-ft. square grate with windbox mounted on four wheels and running on two guide rails. The pan sides are 12-in. high mild-steel plates bolted together, and the suction is provided by a 6-in. dia. pipe connected to a dust-collector leg on No. 3 sinter plant. The last 20 ft. of this pipe is flexible and allows the unit to be moved freely along the guide rails. The igniter is a radiation type of gas-

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Mr. Voice, Mr. Lang, and Dr. Gledhill are members of the Field Trials Section of the Iron Making Division of the British Iron and Steel Research Association.

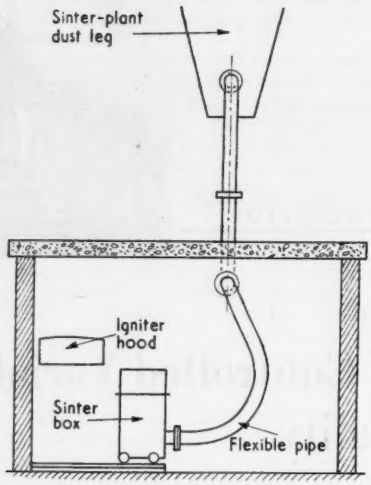


Fig. 1—Original layout of experimental sinter plant

burner using coke-oven gas and is fixed and arranged so that the sinter box can be run under the burner for ignition and then withdrawn without interruption to the air flow through the bed. The igniter, with two sides of the pan removed, is shown in Fig. 2.

As first erected the unit was connected to the suction main of No. 3 sinter plant, and owing to the unavoidable necessity of using a long pipe the maximum suction available at the unit was only 8 in. W.G.

Thermocouples were screwed in the side walls so that, using platinum–platinum/rhodium couples, temperature measurements could be made at four positions in the bed. A base-metal couple was installed in the waste-gas outlet from the box and an aneroid suction gauge was connected just below the grate bars. The couples were connected to calibrated millivoltmeters, and were mounted with the suction gauge and an electric clock on an instrument panel.

The Plant With Suction Control

A Keith Blackman two-stage turbo-blower and exhauster was erected such that, by reversing the sinter box, experiments could be carried out using the original set-up or using the exhauster.

The sinter box was connected to a 6-in. horizontal pipe which could slide through a gland into an L-shaped dustcatcher, so that the sinter box could be run under the ignition hood without using flexible pipes. The dustcatcher was connected to the inlet of the exhauster. As no speed control was fitted to the fan motor, control of the air flow through the bed was obtained by means of a controllable air leak into the dustcatcher, this method having the added advantage of reducing the inlet-gas temperature to the exhauster.

The fan and dustcatcher arrangement is shown in Fig. 3, and with it suctions of up to 32 in. W.G. could be obtained, and up to 24 in. W.G. maintained under the bed throughout the sinter process.

A 4-in. dia. orifice plate was fitted in the horizontal pipe from the windbox so that, after correction for temperature and pressure, air flows could be calculated.

Experimental Procedure

A fairly large quantity of ore, coke, and weathered flue dust was collected and stored under cover. The ore was a Northants greenstone and was screened to $-\frac{1}{2}$ in. before use, whilst the coke was the normal breeze supplied to the sinter plant and was mainly $-\frac{1}{4}$ in. Good-quality return fines were used in the proportion of 75% $\frac{1}{4}$–$\frac{1}{2}$ in. and 25% $\frac{1}{8}$–$\frac{1}{4}$ in. Fuels other than coke were obtained as required.

Sufficient ore, coke, and flue dust were taken from stock, and their moisture contents were determined with a commercial moisture tester giving a dial reading in accordance with the pressure of gas released on contact of moisture with an absorbent. The desired amount of each component, calculated on a dry percentage basis, was weighed out, the whole being well mixed on a concrete floor. The moisture content of the mix was adjusted by spraying with water, remixing, and checking on the moisture tester. The mix was then placed in buckets and poured twice through the Messrs. Stewarts and Lloyds' swinging-hopper mixer, shown in Fig. 4.

The coarse material at the periphery of the pile was loaded on the grate to a depth of about $\frac{1}{2}$ in., and the remaining material was loaded manually. This method of filling appeared to give a reproducible packing, but is considered to be capable of improvement. The pan was filled to a depth of 10 in. and the first inch of mix next to the side walls was tamped down to prevent ignition and act as a seal. The burner was lit, the suction was started, and the sinter box was then pushed rapidly under the igniter. Ignition was continued for $1\frac{1}{2}$ min., the burners were then switched off, and the sinter unit was returned to its initial position.

It was inconvenient to allow the burner to become fully heated before ignition of the sinter, owing to the gas fumes. Adequate ignition was, however, obtained using a cold burner, and this was employed throughout. No experiments were carried out on the effects of good and poor ignition, as it is considered that such trials can be interpreted only if they are carried out on a full-scale plant.

Readings of (1) the temperatures at four positions in the bed, (2) the waste-gas temperatures, and (3) suctions, were taken every $\frac{1}{2}$ min. until the sintering was completed; the suction was then shut off and the sinter allowed to cool. The steel side plates were removed and the loose calcined material adhering to the sinter cake was brushed off. The sinter produced was moved from the pan, given a free drop of 6 ft., and sampled, most of the sinter made being required for this sample. The sinter cake is shown in Fig. 5, and it is clear that the sides had little wall effect on the sinter quality.

The sinter sample was first sieve-analysed to determine the 'as made' size, and was then crushed to $-\frac{1}{2}$ in. and re-sieved. The crushed sinter was then subjected to three assessment tests developed from the original Appleby-Frodingham drop test (*see* Appendix). When the exhauster was in use measurements were taken of bed porosity (*i.e.*, air flow through

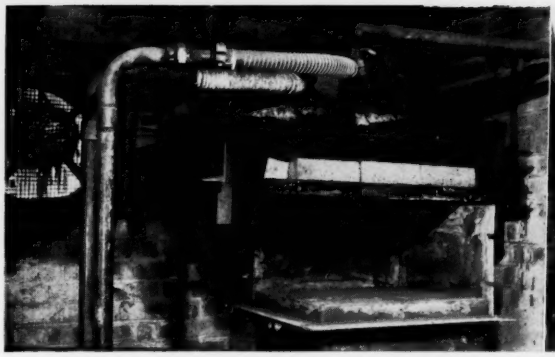


Fig. 2—Sinter box and igniton hood

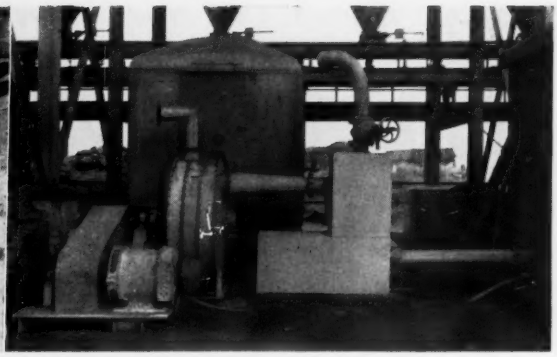
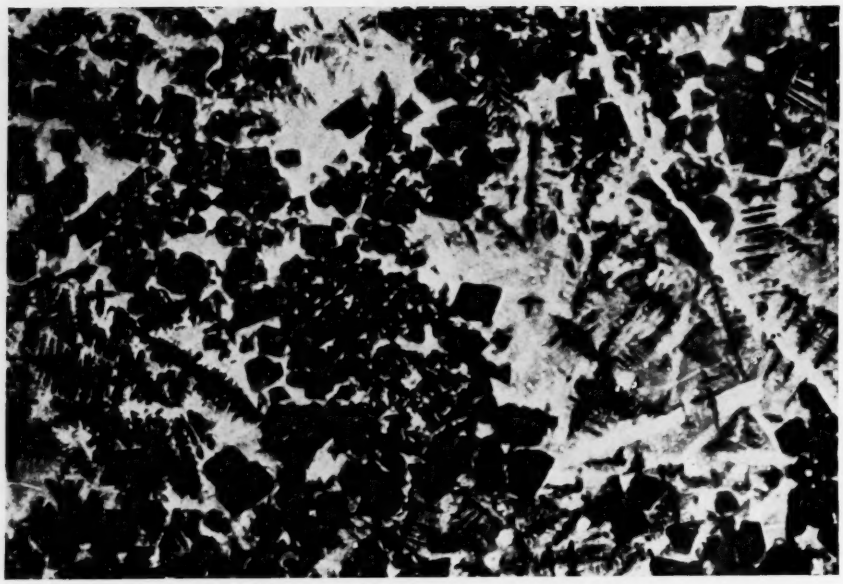


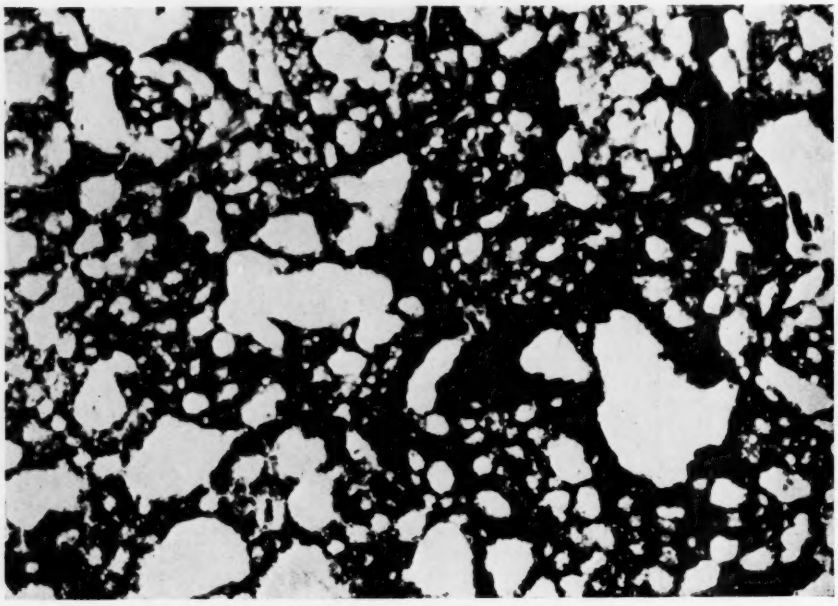
Fig. 3—Sinter fan and dustcatcher

Fig. 4—Device for mixing and balling, designed by Messrs. Stewarts and Lloyds, Ltd.

Fig. 5—Cake of sinter after removing side walls and brushing-off loose material



(a) Serial 4 ; 6% coke. Sintered through, but heavily slagged × 62 linear



(b) Serial 12 ; 4% coke. Sintered through, but friable × 110 linear

Fig. 6—Radiographs of sinter samples

the bed at 16 in. suction) before ignition. A water gauge used across the orifice plate was disconnected during ignition and was reconnected immediately afterwards so that air flow during and after sintering could be ascertained.

When using the plant suction it was found that adequate ignition was easily obtained with 4–8 in. W.G. suction during ignition. With the exhauster in use at suctions above 8 in. W.G. the draught was too great for the burner to give good ignition, and in consequence the suction was always kept at 8 in. during ignition and was increased as desired immediately afterwards.

INITIAL EXPERIMENTS WITHOUT SUCTION CONTROL

Range of Experiments

In initial experiments carried out without suction control, the effects of three variables were investigated as follows :

(1) The coke content was varied between 3% and 7% whilst the flue-dust, return-fines, and total-moisture contents were maintained at 10%, 14%, and 15%, respectively.

(2) The return-fines content was varied between 0% and 50% whilst the coke and flue-dust contents were kept constant at 5% and 10%, respectively. The added moisture was varied as necessary to give a suitable sintering mixture.

(3) The flue-dust content was varied between 5% and 30% whilst the coke, return-fines, and moisture contents were maintained at 5%, 20%, and 15%, respectively.

It was considered desirable to determine the accuracy with which the results could be reproduced, as inaccuracies could arise from : (i) Preparation of the sinter mix from stockpile materials the moisture contents of which varied from day to day. All compositions were calculated on a ' dry ' basis, and thus each material had to be sampled to determine its moisture content immediately before use. Also, the moisture content of the sinter mix had to be adjusted within reasonable limits or the volume of air passing through the bed would have been affected ; (ii) the amount of air drawn through the bed being dependent on the running of No. 3 sinter plant, which affected the suction available at the unit ; (iii) sampling and testing of the sinter ; (iv) variations in loading the charge in the pan.

Sinters were therefore made independently and in

Table I

RESULTS FROM INITIAL EXPERIMENTS WITHOUT SUCTION CONTROL

Serial No.	Date	Raw Materials					Sinter			
		Dry Analysis					Size Analysis As Made		Modified Drop Test	
		Ore, %	Coke, %	Flue Dust, %	Return Fines, %	Total Moisture, %	+ ½ in., %	− ¼ in., %	Dust Index	Strength Index
					Series I					
1	3/4/50	69	7·0	10·0	14·0	15	72·0	8·8	11·0	71·0
2	17/4/50	69	7·0	10·0	14·0	15	85·5	4·2	9·3	78·3
3	23/4/50	69	7·0	10·0	14·0	15	75·0	6·1	10·7	75·0
4	6/4/50	70	6·0	10·0	14·0	15	88·5	3·6	8·3	80·6
5	31/5/50	70	6·0	10·0	14·0	15	87·3	3·7	9·3	79·0
6	1/6/50	70	6·0	10·0	14·0	15	79·4	4·7	11·3	70·7
7	14/4/50	70·5	5·5	10·0	14·0	15	81·2	4·6	10·0	77·7
8	4/4/50	71	5·0	10·0	14·0	15	60·3	9·3	14·7	64·7
9	18/4/50	71	5·0	10·0	14·0	15	63·9	5·1	15·0	61·7
10	24/4/50	71	5·0	10·0	14·0	15	59·5	9·0	16·7	59·0
11	13/4/50	71·5	4·5	10·0	14·0	15	59·6	8·5	15·3	64·3
12	5/4/50	72	4·0	10·0	14·0	15	35·2	15·9	18·3	53·3
13	24/4/50	72	4·0	10·0	14·0	15	51·4	10·5	19·0	53·7
14	24/4/50	72	4·0	10·0	14·0	15	52·5	13·0	18·7	56·7
15	12/4/50	73	3·0	10·0	14·0	15	40·5	21·0	22·0	48·3
					Series II					
16	28/4/50	85	5·0	10·0	0	15	33·6	23·0	24·0	46·7
17	4/5/50	78	5·0	10·0	7	15	45·6	13·2	21·3	52·0
18	24/4/50	65	5·0	10·0	20	15	62·9	7·4	14·3	66·0
19	25/4/50	55	5·0	10·0	30	12·5	65·5	10·4	15·7	63·7
20	9/5/50	55	5·0	10·0	30	14	68·5	6·5	13·3	69·0
21	26/4/50	45	5·0	10·0	40	13	78·4	3·4	10·0	77·3
22	10/5/50	45	5·0	10·0	40	14·5	74·4	5·3	11·7	72·0
23	27/4/50	35	5·0	10·0	50	14·5	71·5	3·5	12·3	71·0
24	8/5/50	35	5·0	10·0	50	12·5	81·7	3·2	10·3	76·3
					Series III					
25	3/5/50	70	5·0	5	20	15	39·9	14·6	19·7	51·7
26	2/5/50	60	5·0	15	20	15	54·8	8·0	12·7	69·0
27	4/5/50	55	5·0	20	20	15	53·5	10·7	13·7	67·3
28	11/5/50	55	5·0	20	20	15	67·8	8·1	11·0	74·7
29	25/5/50	55	5·0	20	20	15	78·3	5·5	9·7	77·3
30	22/5/50	45	5·0	30	20	15	91·3	2·7	7·0	84·3

triplicate at coke contents of 4%, 5%, 6%, and 7%, and the scatter of results was determined.

Results Obtained

The results are given in Table I, and the physical properties of the sinters are plotted against the coke, flue-dust, and return-fines contents, in Fig. 7. An interesting feature of the results, as may be seen by comparisons in Fig. 7, is that the as-made size gave a good indication of the sinter quality.

Increasing the coke content of the mix from 3% to 6% resulted in a progressive improvement in the sinter quality but—rather surprisingly—further increases of the coke content up to 7% caused no further improvement in quality (Fig. 7*d*). A possible cause of this was that the top of the bed slagged, reducing the air flow through the bed, and in consequence the coke would be burnt more slowly and a lower sintering temperature would be obtained. The sinters produced with coke contents of less than 4% were very friable and contained a considerable proportion of calcined material.

The results were used to provide a general comparison between the sinters produced on the small unit and those from the full-scale No. 3 plant. The earlier trials on the production plant showed that a relationship existed between the dust index of the sinter and an index termed the 'effective carbon content' of the mix. 'Effective carbon' indices were calculated from the present results and are shown plotted against the dust indices in Fig. 8. It can be seen that most of the results fall inside the 5% confidence limits calculated from the results obtained on the full-scale plant, confirming that sinters made on the small unit can be directly compared with production sinters. In consequence, improvement in sinter quality brought about by changes on the smaller unit should be directly applicable to full-scale practice.

Increasing the flue-dust content of the mix whilst maintaining the coke content constant resulted in an improvement in sinter quality (Fig. 7*f*), but some care is needed in the interpretation of the results, since, although a fixed coke content was used, the carbon content of the mix was by no means constant, as the flue dust contained 14% of carbon. The observation that increasing the flue-dust content of the mix improves the strength of the sinter confirms the finding from the production plant. Whilst the carbon in the flue dust is effective as a fuel, from these results it is estimated that the carbon in the flue dust is only 60% as effective as carbon in the coke.

It would be expected that increasing the content of return fines would result in an improvement of the physical properties of the sinter, since the heat requirements of the mix have been diminished. Heat must be provided by the fuel to drive off the added moisture from the mix and to remove the combined moisture and carbonaceous material present in considerable quantities in Northants ore. Increasing the quantity of return fines diminishes the amount of water that must be added to give a permeable mix, and reduces the quantity of ore in the mix. The results showed that the quality of sinter was improved as the proportion of return fines was increased. As can be seen from Fig. 7*e*, replacement of ore with up to 15% of return fines caused a rapid increase in sinter strength, whilst further additions brought about a more gradual improvement. The initial rapid improvement is probably associated with the large increase in bed permeability when return fines are introduced to the mix.

The variation in the quality of the sinters produced from nominally similar mixes was rather greater than was anticipated. At 7%, 6%, 5%, and 4% of coke the spread of strength indices was 5·5%, 12·5%,

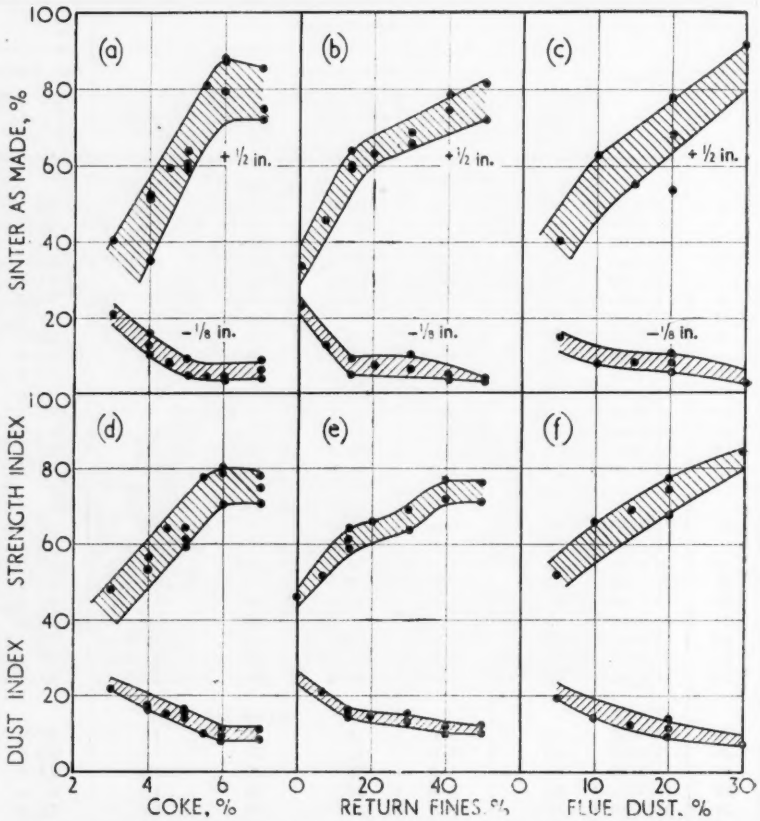


Fig. 7—Results from original experiments without suction control. (*a*) and (*d*) Series I; (*b*) and (*e*) Series II; (*c*) and (*f*) Series III

9·2%, and 6·2% from the respective means. It is, however, expected that in future experiments, with control of suction, better reproducibility will be obtained, as it was evident that in some of the experiments the suction available at the unit was only just sufficient to draw the flame front through the bed.

Physical Nature of the Sinter Produced

Samples of sinter were sectioned for radiographic study, single lumps about 2 in. in diameter being chosen from Serials 4 and 12. Both Serials contained 10% of flue dust and 14% of return-fines, while Serial 4 had 6% of coke and Serial 12 had 4% of coke. The radiographer's report was as follows :

> Two samples of sinter were received, one, Serial 4, looking slaggy and dense, suggesting overfiring, and the other, Serial 12, friable and crumbly, appearing to have been fired insufficiently.
>
> Thin-section radiographs were prepared from the two samples and examined under the microscope, and are reproduced in Fig. 6. *Based purely on this examination* the following comments can be made : The sinter from Serial 4 consists of a mass of well-formed crystals and dendrites of magnetite which are embedded in a glassy matrix. The matrix is essentially free from iron, nearly all the iron occurs as magnetite but there are a few scattered crystals of fayalite (iron olivine). The latter represent a very small proportion of the total iron content. The magnetite crystals are well-formed octahedra up to 0·15 mm. in diameter and can be clearly recognized by their rhomb shape in the accompanying photograph. The ' feathery ' outlines of the dendrites are also clearly visible. The crystals and dendrites together form a loose and porous aggregate which should be easily penetrated by gases, since the glassy matrix would crack up on reheating.

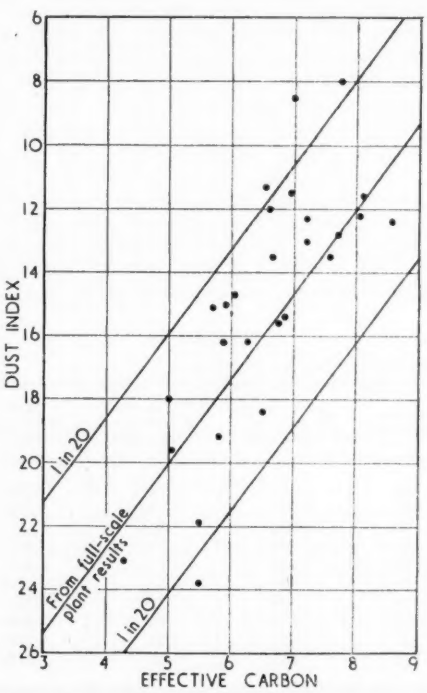


Fig. 8—Relationship between effective-carbon and dust indices

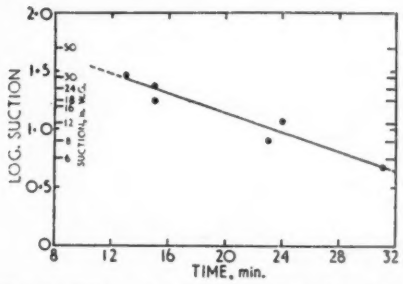


Fig. 9—Effect of suction on sintering time

Reducibility of the sinter would be expected to be good because most of the iron is present as magnetite. In the sample from Serial 12 the process of sintering has only just started and has not proceeded far enough to obliterate the original structures of the raw mix. The photograph shows clearly the rounded outlines of oolitic grains and, although the redistribution of iron has started, no appreciable crystal growth can be seen anywhere. The rims around some of the larger holes and cavities (where temperatures must have been higher than inside the solid material) show the beginning of minute crystal growth. It should be borne in mind that the linear enlargement of the corresponding photograph is nearly twice that of the preceding one. Most of the smaller holes in this section were produced during slicing by the tearing-out of loose grains, and do not represent the porosity of the material. No appreciable separation of iron oxides and slag-forming constituents has yet taken place.

INITIAL EXPERIMENTS WITH CONTROLLED SUCTION AND MEASURED AIR FLOW THROUGH BED

Range of Experiments

The experiments described in this section were carried out to determine the factors influencing the time to sinter a basic sinter mix. The mix contained 5% of coke, 10% of flue dust, and 14% of return fines, calculated on a dry basis, and the effects of (i) suction, (ii) moisture, and (iii) fuel were respectively studied as follows :

(i) The moisture content was maintained constant at 15% and experiments were performed at suction values of 8 in., 12 in., 18 in., 24 in., and 30 in. W.G.

(ii) Five experiments were carried out with mixes containing 14%, 16%, 18%, 20%, and 22% of moisture, respectively, the suction being maintained constant at 16 in. W.G. in each case.

(iii) Experiments were performed using coal, anthracite, oil, and sawdust, respectively, in place of coke breeze. The suction was maintained constant at 16 in. W.G., and the moisture content was adjusted to give a permeable mix.

Four miscellaneous experiments were also carried out, in two of which ore of selected size grading was employed, the third used a mix containing no flue dust, and in the fourth the mix was air-dried on the bed before ignition.

In each case the time to sinter was taken as the time from the start of the ignition to the time when the maximum waste gas temperature was attained.

Results Obtained

The results showed that as the suction applied to the unit was increased, the time to sinter was de-

Fig. 10—Effect of moisture on sintering time

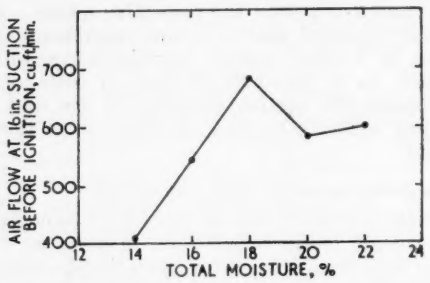


Fig. 11—Relationship between air flow and moisture content of mix

creased. This effect is to be expected, since increasing the suction increases the air flow through the bed and thus enables the coke to be burnt more quickly. The results indicate that the time to sinter is directly proportional to the logarithm of the suction applied (Fig. 9). (A previous result at $4\frac{3}{4}$ in. W.G. is also included). This suggests that the use of very high suction values to increase production would be expensive, since whilst increasing the suction from 10 in. to 30 in. W.G. reduces the sintering time from 24 min. to 12 min., *i.e.*, doubles the rate of production, a further increase to 50 in. W.G. would be expected to reduce the sintering time to $7\frac{1}{2}$ min., *i.e.*, increase the rate of production by about 60%.

The effect on the time of sintering of varying the moisture content of the mix is illustrated in Fig. 10, and it can be seen that there is an optimum moisture content of about 18% when sintering a Northants greenstone. The results also suggest that when sintering this ore the tolerance of moisture content should be from 17% to 19%. It must be emphasized that these results apply only to a Northants greenstone and that with other ores a different optimum moisture content will be expected and the tolerance range may be smaller. This optimum moisture content is connected with an optimum bed permeability, as can be seen from Fig. 11, which shows the air flow through the mix at a fixed suction value, plotted against the moisture content of the mix.

The effect of the different types of fuel is illustrated in Table II and, apart from the sawdust, the fuels, compared with coke breeze, increased the sintering time. Although sawdust decreased the sintering time the sinter produced was extremely friable and consisted mainly of calcined material. Also, owing to the great bulk of the sawdust, the quantity of ore sintered was low.

No decrease in sintering time was obtained when using specially sized ore, but the mix containing no flue dust sintered in 10 min., as compared with 14 min. when using 10% of flue dust, and the bed was highly permeable to air. The influence of flue dust on speed of sintering merits further investigation.

The measured gas flow through the bed throughout a typical experiment is shown in Fig. 12. Immediately after ignition the gas flow is reduced and does not attain its original value until the flame front reaches the grate. There is then a rapid increase in the flow and the final value, through the cold sinter, is sometimes three times the initial figure. The reduction in gas flow is possibly due to moisture condensing in the bed immediately ahead of the flame front, where there is a very steep temperature gradient. These results are of interest in showing that a large proportion of air drawn through a Dwight-Lloyd plant must be utilized in cooling the sinter.

A sinter was made under conditions such that a constant air flow was maintained throughout the sintering process. When set up before ignition, the air flow was measured at 8 in. suction. In order to obtain this air flow it was necessary to use 24 in. W.G.

Table II

EFFECTS OF VARIOUS FUELS ON SINTERING TIME

Serial No.	Date	Type of Fuel	Fuel Used, %	Total Moisture, %	Suction, in. W.G.	Air Flow at 16 in. W.G., cu. ft./min.	Time to Max. Waste-Gas Temp., min.	Max. Waste-Gas Temp., °C.
1	10/7/50	Coal	$4\frac{1}{2}$	18	16	615	14	280
2	11/7/50	Coal	$5\frac{1}{4}$	18	16	697	$14\frac{1}{2}$	250
3	12/7/50	Anthracite	4	18	16	693	Slow	...
4	13/7/50	Sawdust	8	24	16	506	11	180
5	14/7/50	Sawdust + coke	$3\frac{1}{4} + 4$	22	16	541	$12\frac{1}{2}$	250
6*	18/7/50	Coke	$6\frac{1}{2}$	17	16	556	$14\frac{1}{2}$	390
7†	20/7/50	Coke	6	12·5	16	598	17	330
8‡	21/7/50	Coke	$6\frac{1}{2}$	17	16	776	10	250
9§	24/7/50	Coke	6	17·5	16	620	14	290
10	25/7/50	Oil	4	n.d.	16	693	16	310

* Ore — $\frac{1}{4}$ in.; return fines — $\frac{1}{4}$ in.; 1-in. hearth layer
† Ore — $\frac{1}{4}$ in. + $\frac{1}{8}$ in.
‡ No flue dust
§ Air-dried 15 min. at 8 in. suction
n.d. = not determined

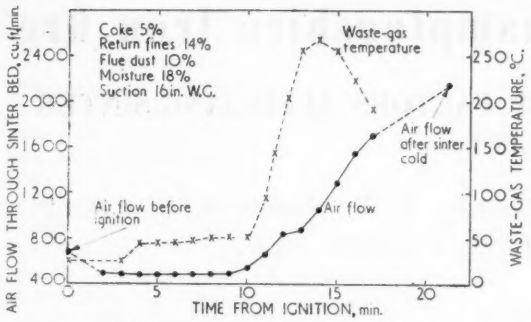


Fig. 12—Gas flow through bed

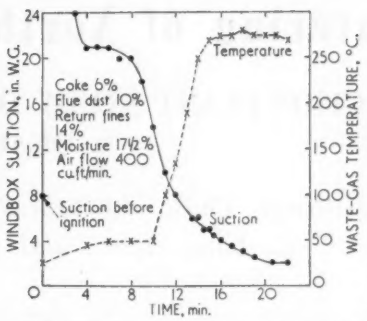


Fig. 13—Variation in suction with constant air flow

suction 3 min. after ignition, and at the end of sintering only 2 in. W.G. of suction were required. The results are shown in Fig. 13 and stress the need for high suction on the first part of the bed and high air flow for the latter part in order to produce cool sinter quickly.

CONCLUSIONS

As a result of the investigation described, the following conclusions were drawn with reference to the sintering of Northants fines :

(1) Sinters produced on the small unit show good correlation with sinters produced on No. 3 sinter plant, Corby.

(2) Increasing the coke content of the mix up to 6% improves the physical quality of the sinter.

(3) At a fixed coke content, increasing the flue-dust content of the mix improves sinter quality. The carbon in flue-dust is about 60% as effective as carbon in the coke.

(4) At fixed coke and flue-dust contents increasing the return-fines content of the mix improves sinter quality.

(5) Increasing the suction reduces the sintering time. The sintering time is inversely proportional to the logarithm of the suction.

(6) When sintering Northants greenstone there is an optimum moisture content of 18%, with a tolerance range from 17% to 19% of moisture.

(7) No advantage was found in the use of fuels other than coke.

APPENDIX

Development of an Improved Impact Test for Sinter

The standard Appleby-Frodingham impact test for sinter has been compared with a modified impact test which uses the same equipment.

STANDARD APPLEBY-FRODINGHAM TEST

The standard Appleby-Frodingham test consists of taking 300 g. of a proportional size analysis, placing this in a circular anvil $5\frac{5}{8}$ in. in diameter, and covering squarely with a dead-weight closure. The sample is then subjected to two impacts from a 10-lb. pear-shaped weight falling freely from a height of 4 ft. The change in size analysis is expressed by two different indices relating to the reduction in the larger fraction and the increase in the dust fraction.

The proportional size analysis is that obtained by taking about 50 lb. of a representative sample of the sinter to be tested, crushing to $-\frac{1}{2}$ in. in a small jaw crusher, and determining the new size analysis. At least three 300-g. samples of the crushed material are taken for the impact test. The results obtained are expressed in the two forms :

$$\text{Dust index} = \frac{(W_1 - W_2) \times 100}{W_3} \quad \ldots\ldots\ldots\ldots(1)$$

where W_1 is the weight of $-\frac{1}{8}$-in. material after impact, W_2 is the weight of $-\frac{1}{8}$-in. material before impact, and W_3 is the weight of $+\frac{1}{8}$-in. before impact.

$$\text{Strength index} = \frac{W_4 \times 100}{W_5} \quad \ldots\ldots\ldots\ldots(2)$$

where W_4 is the weight of $-\frac{1}{2} + \frac{1}{4}$-in. material after impact and W_5 is the weight of $-\frac{1}{2} + \frac{1}{4}$-in. material before impact.

MODIFIED IMPACT TEST

The equipment used in the modified impact test is similar to that in the Appleby-Frodingham test. The difference is that 300 g. of the $-\frac{1}{2}$-in. $+\frac{1}{4}$-in. crushed material is used, and not a proportional sample. The results are expressed simply as :

(1) Dust index = Percentage $-\frac{1}{4}$ in. after impact.
(2) Strength index = Percentage $-\frac{1}{2}$ in. $+\frac{1}{4}$ in. after impact.

COMPARISON OF THE TWO TESTS

The main questions were, firstly, which test is the more reliable and, secondly, which is the more sensitive.

Seven sinters of different physical quality were obtained, crushed to $-\frac{1}{2}$ in., and samples for the two tests were taken. In addition to the normal two drops, tests were carried out giving separate samples four, six, and eight drops. A new strength-index/dust-index ratio was also calculated.

From the results it was evident that the modified test gives a more reliable result, with greater sensitivity. The effect of increasing the number of drops showed that two or four drops were adequate.

THE MODIFIED TEST PROCEDURE

The test will be carried out using the modified impact test, giving separate samples two and four drops. The allowed scatter between any two tests in the same group will not exceed 4%. Dust and strength indices and the strength-index/dust-index ratio will be reported.

Acknowledgments

The authors thank the management of Messrs. Stewarts and Lloyds, Ltd., for their co-operation ; Mr. D. Meachin and Mr. J. B. Remwich, of the Field Trials Section, who carried out much of the experimental work, and Mr. Cohen for the radiographic examinations.

The Sintering of Northamptonshire Iron Ore

A PRODUCTION-PLANT STUDY OF FACTORS AFFECTING SINTER QUALITY

By D. W. Gillings, Ph.D., A.R.I.C., F.Inst.P., E. W. Voice, B.Sc., A.Inst.P., C. Lang, B.Sc., and P. K. Gledhill, Ph.D.

SYNOPSIS

The No. 3 sinter plant at the Corby works of Messrs. Stewarts and Lloyds, Ltd., was made available to a team of investigators from the British Iron and Steel Research Association for full-scale experiments designed to determine the factors which control the quality of sinter made from Northamptonshire iron ores. In order to determine as far as possible a method of assessment of sinter quality, a rudimentary analysis was made of data on the use of sinter of known properties in the burdens of several blast-furnaces, and this emphasized the importance of physical properties. From the results of experiments carried out on the sinter plant it was possible to determine the effects and relative importance of the factors governing the physical properties of the sinter. The control of proportions and properties of raw materials was most important, the carbon content of the raw mixture being especially critical. The efficiency of mixing and the exclusion of large fragments of ore and coke were next in importance, followed by control of content of returned sinter and of water in the mixed raw materials. Variations of suction had very little effect over the range of values encountered on the plant concerned.

Introduction

SINTERING is a means of preparing iron-ore fines, screened from lump ore, for subsequent use in the blast-furnace. The process is almost universally carried out on a down-draught grate, which is either stationary, as in the Greenawalt plant, or moving as in the Dwight-Lloyd machine. The fine ore is mixed with fine coke, flue dust, and other iron-bearing materials such as scale, and the mixture is ignited. The fuel burns under the influence of the induced draught and the mass approaches fusing point, thus forming an agglomerate.

The process has been used for many years at a number of plants in this country. The practice at each plant has generally been evolved to meet the particular condition of operation, but an interest in the technical factors that govern the production of a sinter of good quality has become very widespread. The interchange of experience and information between the operators of sinter plants has led to the appreciation of a number of problems of a general nature encountered in some form at every plant. On this basis it has been realized that investigation of the mechanism of the process and of the factors governing the quality of sinter was needed by the industry, and the present series of trials was accordingly commenced.

Origins of Full-Scale Trials

Co-operative research in the form of full-scale plant trials on the sintering of iron ores had their origin in this country in two informal conferences arranged by the Iron and Steel Industrial Research Council in the years 1943 and 1944. At the first of these meetings practical plant details and experience were reviewed, and at the second the results obtained by scientific workers in the laboratory were discussed. It may be said that a general feeling arose that the laboratory approach was to some extent remote from the problems of the plant, and the suggestion that a series of plant trials should be initiated was therefore put forward. It was further suggested that current sintering practice should be examined at all plants and that those plants producing the most satisfactory sinter should be fully described, with a view to raising the general level of quality. This never proved practicable, because no operator had at that time put forward in precise terms any definition or specification of a good sinter, or stated specifically the properties which render a sinter unacceptable, although operators were experiencing considerable variation of sinter quality. On the basis of this experience it was believed that good sinter must be free from unsintered material and from 'dust' as made, and must resist shatter and abrasion into 'dust.'

The laboratory work which had been carried out on the properties of sinters put the emphasis mainly on the chemical nature and reactivity of the material, leading to an alternative criterion of quality, namely, the possession of a reducibility not inferior to that of the ore from which the sinter was made. However, because of the conditions under which the laboratory tests had been made, effective relation of the physical properties of these sinters to the product from a full-scale plant was not possible.

Saunders and co-workers[1] prepared a number of sinters by using finely divided and well-blended mixtures of ore and carbon and subjecting these to

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selected temperatures for known times. A wide range of conditions, from fritting to complete fusion, was thus observed, and the nature of the bonding was studied. The existence of three main classes of bonding material, namely oxide, ceramic, and iron silicate, was recognized as important, and the possible control of these by temperature of sintering and chemical composition of raw materials was indicated. Specific studies were also made of the effects of size grading and water content on the porosity of the raw-material bed, and these indicated that the latter factor might be critical. Further, it was found to be impossible to sinter uniformly when the maximum size of raw materials exceeded $\frac{1}{8}$ in.

Hay and McLeod[2] made extensive use of micrographic analysis to study the sintering mechanism, and observed the formation of iron oxide eutectic bonds without fusion. The dependence of sinter strength on carbon content of raw materials and on effective temperature was demonstrated, and the possibility of using lime to control reducibility was also studied, practical trials being carried out, but it was generally observed that improvement of reducibility is obtained only at the expense of physical strength. Laboratory and semi-scale trials in which conditions for sulphur removal were studied have also been reported,[3] the results mainly emphasizing the im-

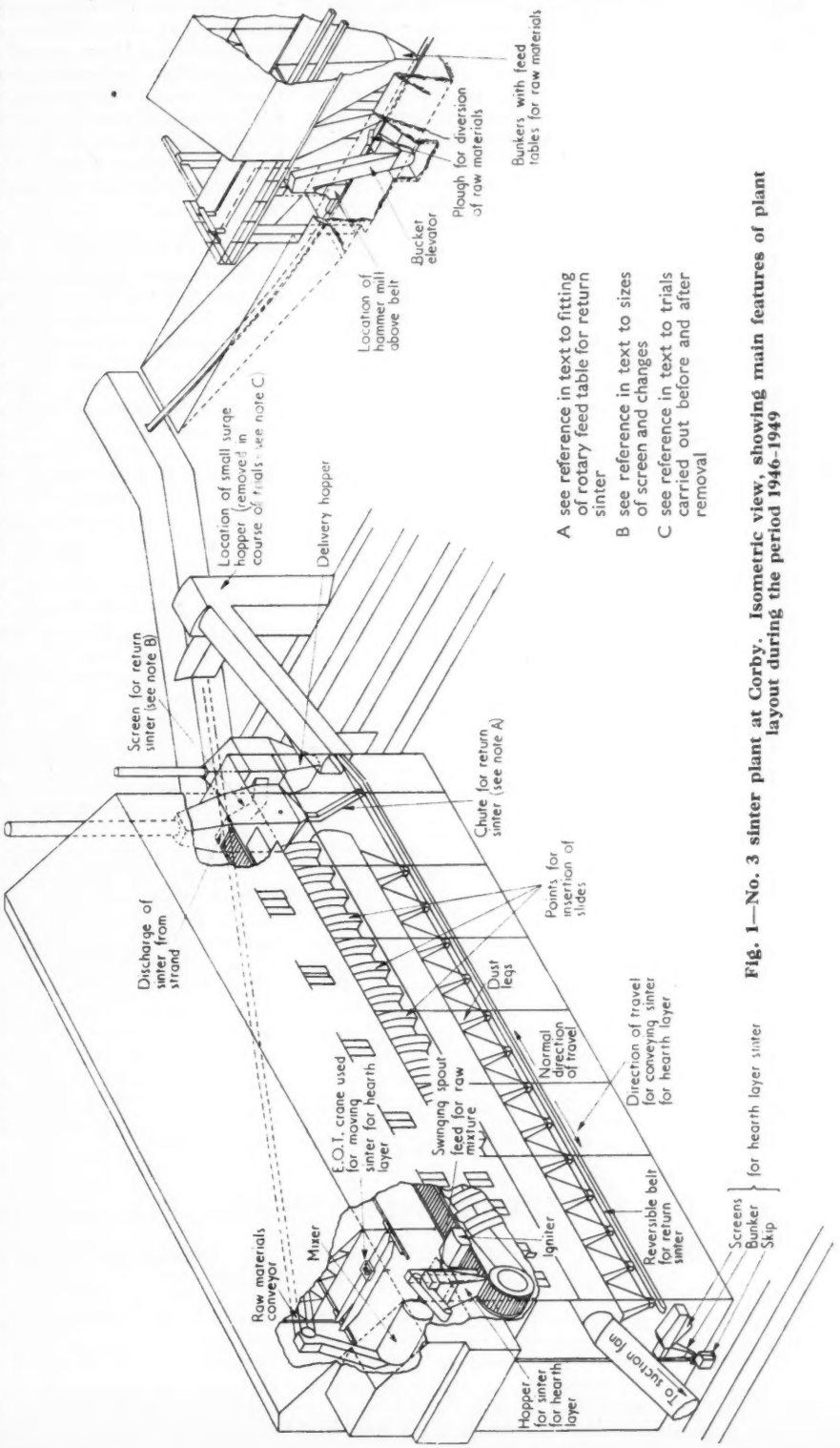
Bunkers with feed tables for raw materials
Plough for diversion of raw materials
Bucket elevator
Location of hammer mill above belt
Location of small surge hopper (removed in course of trials—see note C)
Delivery hopper
Screen for return sinter (see note B)
Chute for return sinter (see note A)
Points for insertion of slides
Discharge of sinter from strand
Dust legs
Normal direction of travel
Direction of travel for conveying sinter for hearth layer
E.O.T. crane used for moving sinter for hearth layer
Swinging spout feed for raw mixture
Raw materials conveyor
Mixer
Igniter
Reversible belt for return sinter
Screens
Bunker
Skip
for hearth layer sinter
To suction fan
Hopper for sinter for hearth layer
A see reference in text to fitting of rotary feed table for return sinter
B see reference in text to sizes of screen and changes
C see reference in text to trials carried out before and after removal

Fig. 1—No. 3 sinter plant at Corby. Isometric view, showing main features of plant layout during the period 1946–1949

portance of fine crushing of raw materials in order to avoid an extended sintering time under reducing conditions.

In the laboratory work the reduction of raw materials to fine-mesh size by-passed many of the obvious problems facing the plant operators, such as the process of mixing and the subsequent segregation in handling. A serious difference also existed between the methods of combustion. In the plant, air drawn through the mixture burns fuel to give heat internally, whereas in the laboratory experiments heat was provided externally and under more controlled conditions.

In addition to the laboratory work, pilot-scale experiments had been carried out by Pepper and the staff of Messrs. Stewarts and Lloyds, Ltd.[4] In these tests the equipment used consisted of a single pallet from a Dwight-Lloyd sintering machine, mounted so that normal suction could be applied and the process carried out under conditions approaching those of the production plant. Preparation of raw materials and feed to the pallet were, however, under laboratory control. Indications from results of this work were as follows:

(1) Elimination of $+\frac{3}{8}$-in. ore from the sinter mixture greatly improves the uniformity of the sinter.

(2) Selective mixing, involving some mechanical conditioning, is essential for good and complete sintering.

(3) Lime can be used to control the physical condition of the mixture and the chemical composition and reducibility of the sinter.

(4) In a burden of mixed ore, proper control of carbon content may be difficult. Control of water content of the raw mixture appears to have a significant effect on the physical quality of the sinter.

With the descriptions and results of these trials available, the view was expressed by plant operators that there was a serious deficiency of experimental work relating to actual operating conditions; furthermore, it was agreed that the problems involved in the sintering of home ores were more serious and should be investigated first. Discussions on the choice of a plant at which experimental work could be carried out were therefore commenced by the then newly formed Sintering Sub-Committee of the British Iron and Steel Research Association, and Messrs. Stewarts and Lloyds, Ltd., indicated that they would be willing to make one of the sinter plants at their Corby works available; at this time one of the plants (*see* Appendix I) was idle for one shift per day, and it was thought that much of the experimental work could be done during the non-production shift. This offer was accepted, and subsequently the Sintering Sub-Committee and other groups met at Corby on several occasions to discuss the programme of work. The layout of No. 3 sinter plant at Corby is illustrated in Fig. 1, which shows the main features of the production plant as well as the experimental modifications.

Aim of Full-Scale Trials

An important introduction to all experimental work, and especially to full-scale trials, is the accurate statement of the problems to be solved. The group of plant operators who formulated the original plan of experimental work set out the questions to which answers were required. What, it was asked, are the effects upon sinter quality of size of ore and coke, water content of raw materials, a separate hearth layer, the quantity of air and control of suction, the rate of feed of the raw materials, the bed depth, and the ratio of lime to silica in the ore? What also are the important features in the design of such plant components as the mixing equipment, the ignition equipment, and the screens for the sinter?

One of the earliest subsequent topics of discussion was the assessment of sinter quality. The establishment of a valid and agreed criterion of sinter quality would clearly permit determination of the effects of the plant and process conditions already set out. Ideally this would be based upon the results of controlled experiments using sinters of known quality as part of an otherwise standard blast-furnace burden, and the indices of quality thus established would then be used to assess the effect of the above variables in controlled experiments on the sinter plant. Pursuance of such a sequence proved impossible, however, and the two approaches had to be made together.

Arbitrary but standard indices of quality were evolved at an early stage of the sinter-plant experiments. Samples were then obtained of sinters used at certain blast-furnace plants where the effect of sinter quality on furnace performance could be estimated. The arbitrary indices of quality relating to these sinters were then determined. It will assist in the clear understanding of the sinter-plant trials to deal first with the evaluation of sinter quality from blast-furnace performance, and the evolution of assessment methods, which can then be regarded as sufficiently well established for use in the sinter-plant trials proper.

Part I—EXPERIMENTAL PROCEDURES AND RESULTS

ASSESSMENT OF SINTER QUALITY IN RELATION TO BLAST-FURNACE PERFORMANCE

In order to establish the assessment of sinter quality in relation to blast-furnace performance, samples of sinter were obtained at intervals during the period of the trials from plants where it was possible to observe the furnace operation and to relate either good or inferior furnace working to the sinter. With the object of covering the widest possible range of sinter properties, samples from plants using imported ores were included as well as those from home-ore plants, although the assessments were primarily devised to apply to the latter sinters. The Managements of four concerns (Works *A*, *B*, *C*, and *D*) co-operated in the

provision of such samples, descriptions of the sinters obtained being as follows :

A Samples from everyday production of sinter of very high iron content (65%), with no special control or sampling.

B Samples of a sinter of high iron content (52%), made with hematite fines additional to the local lean ore.

C Samples of sinter of low iron content (37%), taken during a period of experimental operation to obtain a sinter of increased hardness and resistance to breakdown.

D Samples of sinter of 42% iron content, taken from experimental operation at times corresponding to known furnace behaviour.

The physical and chemical properties of these sinters were assessed to give four indices of quality, as follows (*see* Appendix III) :

(1) A measure of the dust in the sinter ' as made ' or ' as charged ' to the furnace, taken as $-\frac{1}{8}$-in. material.

(2) An index of freedom from dust formation during handling.

(3) An index of physical strength.

(4) A comparative reducibility figure to indicate reactivity.

The results, relating quality to observed furnace operation, are set out in Table I.

In addition to these data, which relate to sinters of generally good quality and indicate the relatively small variation in physical properties of good sinters of a wide range of iron contents, other information of a more approximate type has also been available from time to time. This relates to the effects on furnace operation of departures of sinter quality from the levels indicated in Table I. In one such case it was found that the omission of screening of sinter before use, and consequent retention of the dust, caused severe reduction of iron output and a steep rise in coke consumption. In another instance it was found that when a normally strong—though not specially prepared—sinter was replaced by a dusty and weathered product, the amount that could be used in the furnaces was at once much reduced. In an extreme case the presence of 30% of $-\frac{1}{8}$-in. material enforced a reduction of the sinter content of the burden to a maximum of 15% ; with more than this the furnaces would not drive.

Table I

ASSESSMENTS OF SINTER PROPERTIES

Values determined for four Sinters found satisfactory in the Blast-furnace Burden

Code Letter for Works	Origin of Sinter and Behaviour in the Blast-Furnace Burden	Properties Determined by the Assessment Methods				
		Chemical Properties			Physical Properties	
		Iron Content, %	Percentage Reducibility*	Ratio of Iron Oxides to Slag	Dust Index†	Percentage Sinter $-\frac{1}{8}$ in.
A	Sample from everyday production. Such sinter has been found acceptable in a wide range of proportions, and furnace operation on the plant is consistently good	65	90	11/1	13	3·7 as made
B	Sample taken when making sinter with materials enriched with hematite fines. Use of this sinter is associated with satisfactory furnace operation	52	75	2·8/1	14	All screened out before transport to furnace
C	Sample from experimental production of hard sinter free from dust, but of low iron content. It was found possible to maintain economical furnace operation with 50% of this sinter, while only 30% of sinter with greater dust content is normally used	37	58	1·3/1	15	Under 3% as made
D	Sample taken during an experimental period following development work on plant. A clean and hard sinter was produced, and the content acceptable in the furnace burden was double that normally used	42	55	1·7/1	14‡	Under 8% at furnace

* The percentage reducibility is defined as percentage of reduction after 1·6 hr. in hydrogen at 750° C. Details of the method are described in Appendix III

† Dust index is determined as described in Appendix III

‡ Approximate value

Attempts at statistical analysis of data of this type have not given positive results, even when the most extensive existing observations on blast-furnace operations have been available. It has been pointed out that this is a difficulty that is not confined to analysis of the effect of sinter quality, but encountered generally in the study of blast-furnace operating data.

The conclusions reached must be most reserved, and no more can be stated than the general requirements that : (1) The sinter should contain the minimum possible dust when it reaches the furnace, a figure of 5% of $-\frac{1}{8}$-in. material being possible of attainment in good practice, and this value should not be exceeded. (2) The sinter must be strong and resistant to breakdown into dust, and the 'dust index'* should not exceed 15 ; the higher the iron content of the ore fines the more readily are these properties obtained. (3) When assessed primarily by its chemical properties, sinter from home ores at low iron content may be much less reducible than the ore in the burden, provided that it has adequate strength, but if large proportions of sinter are used better reducibility may be beneficial.

These observations are in general agreement with the experience of practical operators ; but significant assessment methods are important in establishing quantitative relations between the reproducible assessments and practical experience.

There is, however, one further characteristic of sinter which is of great importance, namely, the amount of unsintered ore which still remains in the product as delivered to the furnaces. The problem of quantitative assessment of the percentage of unsintered ore received a great deal of attention and a number of methods were suggested and investigated, but none was found sufficiently reproducible for adoption as a standard assessment for all trials. The difficulties encountered with every method arose from the presence of a proportion of partially sintered material, of the same magnitude as that of the unsintered material which was being sought. At later stages of the work attention was drawn to the possibilities of hand-picking as a method of sufficient accuracy, but this was not widely adopted in the trials, since its acceptability was not established until an advanced stage of the trials, when the experimental sinters normally contained only negligible proportions of unsintered material.

Despite this omission, the importance of assessment of unsintered material is still fully appreciated. Although no regular values of assessments are set out in any of the tables of results, references are made in the text to instances in which extreme values of unsintered material were observed.

* *See* Appendix III.

EXPERIMENTAL PROCEDURE IN THE SINTER-PLANT TRIALS

The trials carried out were in approximately the following groups :

(i) Preliminary trials, in which the influence on sinter quality of selected outstanding factors was explored by partial control of sintering conditions. This was obtained by use of batches of selected raw materials, and other empirical arrangements.

(ii) Observations of the variations of plant and process conditions and their relation to fluctuations of sinter quality in normal production.

(iii) Experimental production for short periods with consistently prepared raw materials and control of other plant conditions.

The trials were concurrent with the installation of

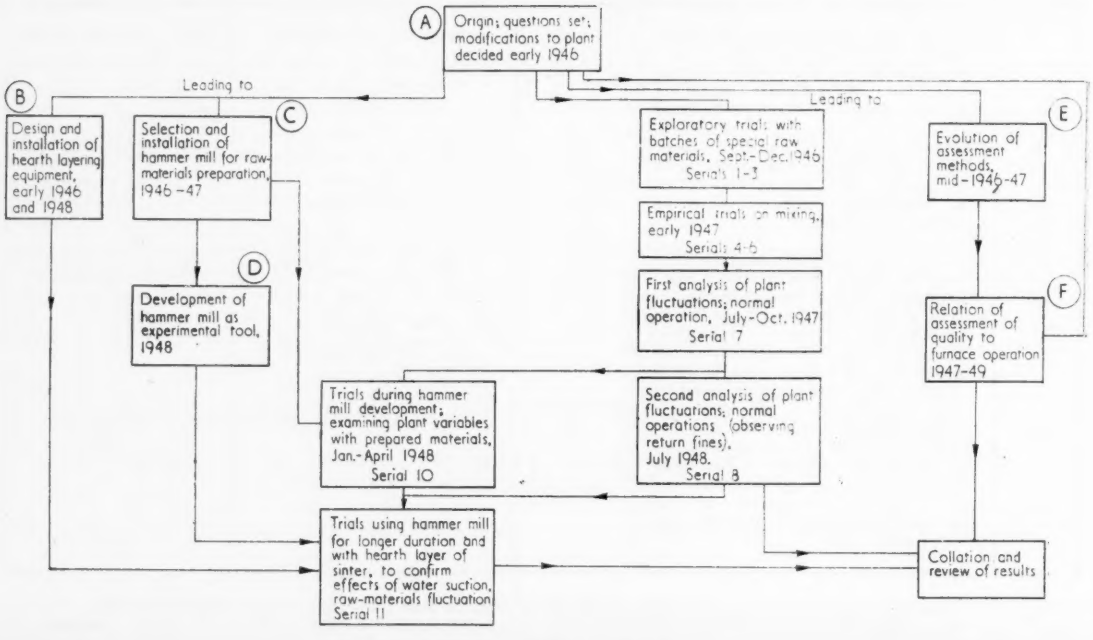
A
Origin; questions set; modifications to plant decided early 1946
Leading to
B
Design and installation of hearth layering equipment, early 1946 and 1948
C
Selection and installation of hammer mill for raw-materials preparation, 1946–47
D
Development of hammer mill as experimental tool, 1948
Leading to
Exploratory trials with batches of special raw materials, Sept.–Dec. 1946 Serials 1–3
Empirical trials on mixing, early 1947 Serials 4–6
First analysis of plant fluctuations; normal operation, July–Oct. 1947 Serial 7
Second analysis of plant fluctuations; normal operations (observing return fines), July 1948. Serial 8
Trials during hammer mill development; examining plant variables with prepared materials, Jan.–April 1948 Serial 10
Trials using hammer mill for longer duration and with hearth layer of sinter, to confirm effects of water suction, raw-materials fluctuation Serial 11
E
Evolution of assessment methods, mid-1946–47
F
Relation of assessment of quality to furnace operation 1947–49
Collation and review of results

Fig. 2—Sequence of trials

experimental equipment to enhance the degree of control obtainable. This equipment included a high-speed hammer mill to prepare raw materials, and also a system for the deposition, for short periods, of screened sinter as a separate hearth layer. As the trials were carried out on a plant which was part of a fully integrated production unit and, further, at a time when there were pressing demands for increased output, it proved impossible to work to one strictly coherent plan. In order to clarify the procedure adopted, a list and diagrammatic presentation of the sequence of trials is given in Fig. 2, which shows approximately the relative order in which each series was carried out and its relation to the preceding and succeeding stages and to the stage reached in the installation of experimental equipment, described in Appendix I. The sequence and subdivision of the series of trials indicated in Fig. 2 were as follows :

Serial Nos. 1, 2, *and* 3—Exploratory trials of short duration, attempting to determine the effect of controlling size of raw materials by using ore and coke from outside sources.

Serial Nos. 4, 5, *and* 6—Trials on semi-scale and production plant, to investigate the effect of variations in mixing.

Serial Nos. 7 *and* 8—Observations of normal operation and the analysis of fluctuations, to relate quality of sinter to plant and process conditions.

Serial No. 9—Experiments conducted under partial control, to investigate effects of change of suction and the incorporation of lime in the raw materials.

Serial No. 10—In this series the treatment of raw materials by the hammer mill controlled the size and the uniformity of mixing, and enabled other variables to be studied.

Serial No. 11—This series was similar to Series 10, but there was, in addition, a separate hearth layer of sinter of controlled thickness.

EXPLORATORY TRIALS (SERIES 1, 2, AND 3)

Since it was not possible at the commencement of the work to install any crushing plant, a number of trials were carried out to determine the effect of restricting the maximum size of ore by using batches of suitable material (about 100 tons at a time) from sources other than the Corby mines. It was anticipated that the elimination of material over $\frac{3}{8}$ in. in size would substantially reduce the content of unsintered material in the finished product. Such experiments were made possible by the co-operation of the Appleby-Frodingham Steel Company, who arranged to supply dried siliceous South Lincolnshire ore screened at $-\frac{1}{4}$ in., and of Messrs. Richard Thomas and Baldwins, Ltd., for Northamptonshire ore from their underground mines at Irthlingborough. In these trials the operation of the plant differed little from normal working. The rates of feed of raw materials were determined as described in Appendix III, samples of raw materials being taken in addition to samples of sinter obtained when operation appeared most representative. Details of the objects, conditions, and procedures in these trials are recorded in Table II ; reference has already been made to the assessment methods used. The size grading, strength index, and reducibility of the sinters were determined as described in Appendix III.

Series 1

Three experiments were made in Series 1, one using dried fines, one using normal Corby fines (both with 5% of partly screened coke but no flue dust), and a third in which normal production sinter was assessed. These experiments were planned on the basis of results obtained in semi-scale trials, the figures from these being used to set the feed rates and predict the water required for raising the moisture content to normal (about 15%). The sinter produced when using the dried ore, however, was not of good quality as judged by physical assessment and general observation, but the reference sinter made from Corby ore was also equally poor. Both products were friable, dusty, and contained much unsintered material. These trials were inconclusive, and were repeated in the next series, added attention being given to the coke requirements.

Series 2

The absence of positive indication from Series 1, that elimination of oversize ore brought about improved sinter, of itself suggested that the attempt to control the full-scale trials from results obtained on semi-scale tests was wrongly conceived. In Series 2 five trials were completed : during the first four, conditions were varied empirically to give optimum sinter quality. In the fifth trial the coke and flue-dust rates were then selected to ensure an adequate total-carbon content on the basis of observations during the preceding trials.

In two of the first four trials dried ore was used, alternating with two control experiments with normal ore, although in every trial the coke was specially selected and free from $+\frac{1}{8}$-in. material. Stronger and more homogeneous sinters were produced in this series than in Series 1, but incomplete sintering was not eliminated, even with screened ore and fine coke. The most notable observation was the increased tendency for the larger lumps of ore to approach the sintered state when using fine coke rather than normal rough breeze.

Series 3

As it was considered that drying the ore for screening possibly rendered it unrepresentative of practice, two trials were carried out using ore fines from the underground mine at Irthlingborough. The ore is a greenstone free from sticky clay and was sized all $-\frac{5}{8}$ in. by screening as mined. Very fine coke (100% $-\frac{1}{16}$ in.) was used in one trial, and coke 100% $-\frac{1}{4}$ in. in the other. The ore sintered very readily, with quite low percentages of coke, and the sinter was apparently superior to that obtained with dried ore.

From the results of the experiments in the first three series the following points seem most significant :

(1) Elimination of oversize material does not of itself eliminate the unsintered-ore content in the final product.

(2) There is some indication that a low fuel content leads directly to under-sintered material.

(3) Some of the incomplete sintering appears to arise from deficiencies of mixing.

Table II

INTRODUCTORY TRIALS: SINTER PRODUCTION FROM RAW MATERIALS OF CONTROLLED SIZE. SUMMARY OF CONDITIONS AND ASSESSMENTS. SERIES 1, 2, 3, AT No. 3 PLANT, CORBY

Serial No.	Objects of Trials		Trial No.	Date	Raw Materials										Observations on Process and Sinter Quality	Assessment of Sinter Produced						
	Series	Individual Trials			Nature and Content				Analysis of Mixture							Estimation of Heterogeneity	Estimation of Quality	Strength Index	Dust Index†	Size Analysis as Made, %		
					Ore	Coke	Coke, %	Flue Dust, %	Fe, %	Fe″, %	SiO_2, %	CaO, %	H_2O, %	C, %						$-\frac{1}{4}$ in.	$-\frac{1}{8}$ in.	$-\frac{1}{16}$ in
1	To explore the effect of eliminating large fragments from the raw materials without special attention to other aspects of the process or plant conditions	Assessment of sinter from dried ore screened at $\frac{1}{4}$ in.	1/1	11/ 9/46	Dried Northants, $-\frac{1}{2}$ in.	Corby; screened at $\frac{3}{8}$ in.	5·2 (set)	0	35·4	4·2	15·4	4·1	13·0	3·8*	The normal sinter, chosen at random, was typical of production at the time; heterogeneous, the sintered matrix being fairly hard, with unsintered ore fragments dispersed unevenly. The experimental sinters were both weak and dusty, with a high unsintered content. The setting of coke at 5% (as for semi-scale) was too low in both cases. The elimination of $+\frac{1}{2}$ in. ore in trial 1/1 did not eliminate all unsintered, and sinter was unexpectedly poor. Mixing appeared defective, and water content was difficult to control	Bad	Bad	32	37	80	58	36
		Assessment of sinter from ore screened at 1 in. with feed rates as in trial 1/1	1/2	9/ 9/46	Corby mixed fines, −1 in. Not dried	Corby; screened at $\frac{3}{8}$ in.	5·0 (set)	0	35	11·6	9·5	7·5	16·0	3·5*		Bad	Bad	41	...	87	53	13
		Standardization by assessment of normal production sinter	1/3	4/10/46	Corby mixed fines, −1 in. Not dried	Corby; production	5	13	33·8	11·6	10·6	8·6	16·7	4·8		Standard	Standard	64	29	67	35	25
2	Extension of previous series to include modifications to process and seek optimum conditions for the selected materials	Repetition of trial 1/1 with rates of feed adjusted during trial	2/1	29/10/46	Dried, $-\frac{1}{2}$ in.	Corby; production	9 (final value)	11	34·0	5·2	14·8	5·8	13·9	7·0*	In this repetition trial with dried fine ore the coke rates were found difficult to stabilize. After 1 hr. running, steady at 9%, but still giving some uneven and unsintered product	As standard	Rather below standard	46	...	57	33	22
		Second standardization with selected coke and rate of feed adjusted during trial	2/2	5/11/46	Corby mixed fines, −1 in. Not dried	Selected. All $-\frac{1}{8}$ in.	6 (final value)	10	34	11·4	11·9	7·0	14·3	6·0	In this second "Standard" a finer coke was used, giving definite benefit by increasing degree of sintering of larger ore fragments	Both rather better than standard		46	...	73	34	21

Table II—(*Continued*)

Serial No.	Objects of Trials		Trial No.	Date	Raw Materials										Observations on Process and Sinter Quality	Assessment of Sinter Produced					
	Series	Individual Trials			Nature and Content				Analysis of Mixture							Estimation of Heterogeneity	Estimation of Quality	Strength Index	Dust Index†	Size Analysis as Made, %		
					Ore	Coke	Coke, %	Flue Dust, %	Fe, %	Fe″, %	SiO_2, %	CaO, %	H_2O, %	C, %						−¼ in.	−⅛ in.	−⅛ in.
2 (cont.)		Repetition of trial 2/1 with further adjustments of coke rate during trial	2/3	19/11/46	Dried, −½ in.	Selected. All −⅛ in.	5 (final value)	12	37	4·0	13·6	3·2	12·5	4·5	All fine materials; dried −½ in. ore and finer coke gave difficulty in control of water content. Sintering was still uneven, but some masses of good completely sintered material obtained	Better	Rather better	45	...	75	42	21
		Repetition of trial 2/2	2/4	29/11/46	Mixed, −1 in. Not dried	Selected. All −⅛ in.	8 (final value)	20	35·4	9·8	10·4	7·9	14·7	3·0	Exceptionally difficult conditions. Very wet ore demanded high flue-dust addition, leading to dusty and heterogeneous sinter, but not unduly weak	Below Standard		44	20	65	32	22
		Assessment of sinter from dried ore screened at ½ in. with predetermined feed of coke of selected size (−½ in.)	2/5	10/12/46	Dried, −½ in.	Selected. All −⅛ in.	7 (set)	10 (set)	33·6	4·6	14·4	4·1	16·3	6·0	By setting coke higher and with easy mixing of fine coke, more homogeneous product obtained. Some unsintered regions of packed "dead" fines persisted. Main mass well sintered	Significant improvement		42	13	45	24	15
3	To explore the effect of eliminating the drying of ore for screening by use of material screened as received from underground mining	Repetition of trial 2/1 without dried ore, but screened at ⅜ in.	3/1	16/12/46	From mine at Irthlingborough −⅜ in.	Selected belt spillage; all −½ in.	3·6	13	30·6	26·0	13·9	5·7	14·3	5·2	The mined ore is free from clay but has some natural water content which ensures regular flowing and easy mixing. Good sinters obtained at lower coke rates. In second trial better results were obtained by slightly coarser coke breeze at higher feed rate. Both this and previous sinter were stronger and more homogeneous than rest of series	Rather better	Normal	52	...	44	22	15
		Repetition of trial 3/1 with fixed coke feed rate	3/2	30/12/46	From mine at Irthlingborough −⅜ in.	Specially screened breeze ex Wellingborough −½ in.	5·0 (set)	13	34·0	26·2	13·9	5·1	16·7	4·4		Rather better	Above standard	43	...	53	23	13

* Calculated value. Approximate † Determination only relative; carried out on samples after storage

EXPERIMENTS ON MIXING RAW MATERIALS (SERIES 4, 5, AND 6)

Following the exploratory trials it seemed clear that factors other than the size analysis of materials exercised control over the quality of sinter. The appearance of pockets of unsintered fines in the product from dried screened ore suggested heterogeneity of the original mixture of raw materials. The next experiments were devised to investigate the extent and importance of the variations that might occur in the mixing process. Three series were completed, the first on a small scale and the second and third on full-scale plant.

Series 4. Semi-Scale Trials

In these trials the object was to compare directly the effect of two degrees of mixing. In one trial the normal mixture from the plant was used, and in the second that from a more thorough mixing in a rotary drum of the concrete-mixer type.

A stationary single-pallet experimental plant carrying about 500 lb. of mixture was made available by Messrs. Stewarts and Lloyds, Ltd. The material was fed evenly on to the pallet, ignited, left to burn and cool, and sampled when cold. Ignition was effected by a gas-heated hood identical with that used in normal production, and the suction available at the time of the trials was about 3 in. W.G.

The details and results are set out in Table III. The main features are the decrease in unsintered material and the increase in strength in the sinter made from thoroughly mixed materials. In a third trial it was observed that under conditions of mixing which caused the fuel to be covered with clay no ignition could be obtained. This failure to ignite was not due to excessive moisture, since drying-out by prolonged heating did not permit ultimate ignition.

Series 5. Survey of Homogeneity of Raw Mixture in the Sinter Bed

A direct determination of the occurrence and extent of heterogeneous chemical composition of the raw material, as deposited by the swinging spout, was carried out by sampling at a number of points in the raw material before ignition, to determine chemically the uniformity of mixing and distribution of materials. The actual sampling was, of course, very simple, but special materials were used to avoid complicating the analysis and its interpretation. The ore was obtained from the Irthlingborough mine, to ensure uniformity of iron content and analysis, and the coke was specially screened — $\frac{1}{4}$ in. No flue dust or return fines were used, since fluctuations in analysis of these were not known. The materials were fed steadily, and when a constant feed was established the machine was stopped and 25 samples, each a few cubic inches in volume, were taken immediately below the swinging spout, as indicated in Table V. This volume was chosen as representing the order of dimension in which uneven sintering occurred. The samples were analysed and the salient feature of the results, namely the variation in carbon content, is shown in diagrammatic form in Fig. 3 (*a*). This experiment was subsequently repeated with material which had been fed through the hammer mill, and the results are shown in the same form in Fig. 3 (*b*). The greatly improved homogeneity is obvious, despite the use of mixed fine ore in the second trial and selected ore in the first trial.

Series 6. Empirical Comparisons of Mixers of Two Designs on Production Plants

The older sinter plants at Corby were provided with paddle mixers as opposed to the plain open-trommel type on the new No. 3 plant. Trials were therefore conducted on the older plants to obtain a comparison, though there were complicating differences between the plants which had to be taken into account. For instance, the strand speeds and suction values were not the same, so that to obtain results with some validity the trials carried out at No. 3 plant for comparison included some with sintering rate and suction approximating to values at the older plants. The observations made are set out in Table IV.

Interpretation of the results was recognized at the time to be uncertain, since the fluctuations of the plant conditions were known to give wide variations of quality. An analysis of these variations carried out later indicated that they would probably be of over-riding importance; nevertheless, with these reservations in mind, the results appeared to show that the sinters produced from the plant with the paddle mixers were stronger and more completely sintered than those from the plant with the open trommel (*see* trials 6/1 or 6/2 and compare with the rest of the series). The effects of the changes in suction and sintering rate appeared to be less than the day-to-day fluctuations during normal operation (*see* trials 6/4 and 6/5, and 6/6 and 6/7). It will be realized that the process required to mix an essentially heterogeneous system such as raw material for sinter is not simple, and the fluctuations in operating conditions make it difficult to observe the effect of mixing exclusively.

After these experiments it was decided not to proceed with work specific to the mixing problems. Arrangements had been made to install a high-speed hammer mill (*see* Appendix II) for preparation of raw materials and, although intended primarily for crushing, this was set up so that some mixing would also be brought about. It was agreed that any further work should await trials of this equipment. In so far as results of these preliminary trials could be regarded as significant, they showed scope for improvement of mixers, but data for the design of an efficient mixer would probably have to be evolved from experiments specific to practice at individual plants.

FLUCTUATIONS OF NORMAL PLANT AND PROCESS CONDITIONS AND THEIR RELATION TO FLUCTUATIONS OF SINTER QUALITY (SERIES 7 AND 8)

Series 7

When the previous trials had been completed a sufficiently satisfactory technique of quality assessment had been established, and it was possible to carry out the first stage of systematic work, namely the undertaking of observations to determine the relationship between variations of sinter quality and of plant and process conditions. During these trials operation was normal and no attempt was made to exercise any control, but measurements were made of the feed rates of raw material, and pallets of sinter were lifted from the strand for assessment of quality

Table III—EMPIRICAL EXPERIMENTS OF MIXING OF RAW MATERIALS

Series 4: Trials using the single-pallet semi-scale plant

Trial	Method of Mixing	Raw Materials: Nature and Composition	Raw Materials: Analysis Fe, %	SiO_2, %	CaO, %	H_2O, %	C, %	Observation on Process and Product	Assessments of Physical Properties of Sinter: Strength Index	Dust Index	Size Analysis, % −1 in.	Size Analysis, % −¼ in.
4/1	As on No. 1 plant, Corby	As from plant strand; ore 88%, coke 8%, flue dust 4%	34	10·9	7·2	19	6·6	Required larger ignition time than on plant, but product normal	68	13	72	6
4/2	Components in sequence ore first, coke next, in rotary concrete mixer	Made up to simulate material in trial 4/1	33	12·0	6·2	19*	6·0	Impossible to ignite, despite drying-out of material and sufficient carbon content	No sinter			
4/3		Made up to simulate material in trial 4/1, but with extra 20% return fines	33	12·6	7·3	18	7·4	Ignited and sintered well, giving hard thoroughly sintered product with large lumps of ore (1 in. reacted and fritted hard right through)	81	11	47	6

* Initial figure; dried out to less than 10% in attempts to ignite

Table IV—EMPIRICAL EXPERIMENTS OF MIXING OF RAW MATERIALS

Series 6: Full-scale trials at the Corby production plants with two types of mixer

Trial	Plant	Type of Mixer	Information Sought	Variables Studied	Raw Materials: Content Ore, %	Coke, %	Flue Dust, %	Analysis Fe, %	SiO_2, %	CaO, %	H_2O, %	C, %	Description of Sinter	Assessment of Physical Properties of Sinter: Strength Index	Dust Index	Size Analysis, % −1 in.	Size Analysis, % −¼ in.
6/1	No. 2	Open-drum and internal-paddle	"Standard" of quality of sinter made with this type of mixer	Type of mixer for direct comparison with trommel in trial 6/3	Not determined			30·6	12·8	8·7	...	10·7	Strong and completely sintered; process was at low suction for long duration	75	10·8	30	4
6/2	No. 1							34·4	13·0	8·3	...	3·4	More homogeneous than subsequent samples from No. 3 plant	51	13·7	43·6	7·0
6/3	No. 3	Open trommel, with vanes.	Preliminary "standard" for this type of mixer	Trommel-type mixer with feed rate as in trials 6/1 and 6/2, for direct comparison	Not determined									46	21	87·7	8·4
6/4			Relative effect of mixer type and other plant differences in comparing Nos. 1, 2, and No. 3 plants	As in trial 6/3, for "standard"	91·6	3·5	4·9	31·6	15·2	8·1	16·16·5	3·7	All sinters from No. 3 plant were qualitatively similar although of variable strength. In no case was unsintered content much altered	52	19	84·3	13·9
6/5				Flow rate reduced to approximate trials 6/1 and 6/2	90·5	3·9	5·6	35·8	13·0	6·9	12–15	3·3		58	18	82·0	19·5
6/6				"Standard"	84·4	7·2	8·4	32	11·0	7·0	14·5–16	8·2		63	16	73·7	11·3
6/7				As trial 6/5, but also reduced suction	83·8	7·0	9·2	34	11·4	6·2	15·5–17·5	7·4		60	18	78·6	10·8

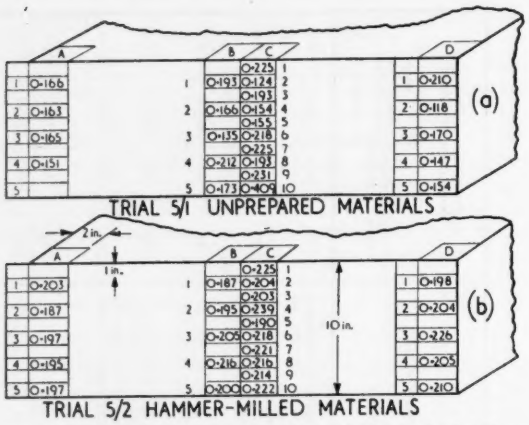

Fig. 3—Diagram of cross-section of sinter bed below swinging spout, showing sampling positions and carbon/iron ratios

at times corresponding to the times of sampling raw materials.

Experimental Procedure—The rates of feed of the raw materials were obtained by direct weighing of a tray on the feed belt carried under the delivery from the required feed table, and representative samples of the ore fines and coke were taken from the tray for size analysis. If the feed of raw material was fluctuating badly, observations were delayed, but fairly wide fluctuations always occurred between individual tray samples, and a number of observations were therefore always made. Details of the sampling method are given in Appendix III.

During this series only two investigators were available, and observations on the raw materials and the sinter strand could not proceed simultaneously. As soon as possible after the feed rate was determined, however, a bucket sample of the mixture representative of a particular pallet was obtained as the feed entered the swinging spout. This sample was retained for size analysis after a sample for complete chemical analysis had been obtained by coning and quartering. Snap samples of the mixture were also taken to determine the moisture content on drying at 110° C.

When the sample pallet reached the discharge end of the machine the strand was stopped and the pallet was removed by overhead crane. The pallet was allowed to cool and a sample weighing about $\frac{1}{2}$ cwt. was taken, assessments of physical and chemical properties being carried out on this.

Study of Results—The results, which are included in Table VI, were first examined by attempting to set out graphically all possible relations between measured properties of raw materials and sinter quality. Most of the diagrams showed a random arrangement, but some suggested significant relationships, and these were examined statistically. Some of the random plots were unexpected in that previous ideas suggested the likelihood of some relation. Of these the most notable example was that no significant relationship was established between the average size of the raw materials and the sinter quality, expressed as the dust index or as percentage of sinter under $\frac{1}{8}$ in. This is illustrated in Fig. 4, in which the average

Table V

SERIES 5: DIRECT DETERMINATION OF MIXING EFFICIENCY. ABSTRACT FROM ANALYTICAL RESULTS (see also Fig. 3)

Position A	Fe, %	C, %	C/Fe Ratio	Position B	Fe, %	C, %	C/Fe Ratio	Position C (1–5)	Fe, %	C, %	C/Fe Ratio	Position C (6–10)	Fe, %	C, %	C/Fe Ratio	Position D	Fe, %	C, %	C/Fe Ratio
							Trial 5/1. Unprepared Raw Materials												
1	30·8	5·1	0·166	1	30·5	5·9	0·193	1	29·9	6·7	0·225	6	30·8	6·7	0·218	1	30·0	6·3	0·210
2	30·8	5·0	0·163	2	30·2	5·0	0·166	2	30·7	3·8	0·124	7	29·9	6·7	0·225	2	31·1	3·7	0·118
3	31·5	5·2	0·165	3	30·5	4·1	0·135	3	29·6	5·7	0·193	8	30·5	5·9	0·193	3	30·4	5·2	0·170
4	31·0	4·7	0·151	4	29·9	6·3	0·212	4	30·5	4·7	0·154	9	29·9	6·9	0·231	4	30·8	4·5	0·147
5	...	...	...	5	30·5	5·3	0·173	5	30·8	4·8	0·155	10	27·7	11·1	0·409	5	30·2	4·6	0·154
							Trial 5/2. Mixed Hammer-Mill-Treated Raw Materials												
1	32·0	6·5	0·203	1	32·0	6·0	0·187	1	32·0	7·2	0·225	6	32·0	7·0	0·218	1	32·4	6·4	0·198
2	32·0	6·0	0·187	2	32·2	6·3	0·195	2	32·4	6·6	0·204	7	32·6	7·2	0·221	2	32·4	6·6	0·204
3	32·0	6·3	0·197	3	32·2	6·6	0·205	3	33·0	6·7	0·203	8	32·4	7·0	0·216	3	32·2	7·3	0·226
4	32·2	6·3	0·195	4	32·0	6·9	0·216	4	32·2	7·7	0·239	9	32·6	7·0	0·214	4	32·6	6·7	0·205
5	32·0	6·3	0·197	5	32·0	6·4	0·200	5	32·6	6·2	0·190	10	32·4	7·2	0·222	5	32·4	6·8	0·210

ore and coke size for each mix is plotted against the dust index. However, the variation in ore and coke size during normal production is comparatively small, and different results might have been obtained had wider ranges of size been encountered.

No significant relationship was found between sinter quality and (1) the chemical properties of the raw materials, in particular the lime/silica ratio, and (2) the ratio of volatile content (expressed as water content plus percentage loss on ignition) to the total iron content. This was rather unexpected, as preliminary plots tended to show a relation between the dust as made and the ratio of volatiles to iron in the raw materials. In fact, the only valid relation established by statistical treatment was that between the carbon content of the mixed raw materials and the sinter quality.

The main source of carbon is the coke, and the first plots suggested a relation, which proved significant on analysis, between the percentage of coke measured at the feed tables and the dust index. The carbon content is, however, governed not only by the coke, but also by the flue dust and the return-fines delivery. The flue dust contains carbon, and is thus a source of fuel, while the addition of return fines tends to reduce the proportion of carbon in the raw mixture. It might be expected therefore that the carbon content determined directly by analysis of the mixed materials would be the best figure to use in the derivation of any relationship. Such a relationship can be derived, but it was found that greater significance attached to a measure of carbon content which took account of the coke input rate as well as the carbon content obtained by analysis. Such an empirical measure of the carbon content, designated as "effective carbon content," was expressed as the mean between the coke feed rate and the analysed carbon percentages. This figure appeared to give the most reliable basis for assessing whether a deviation

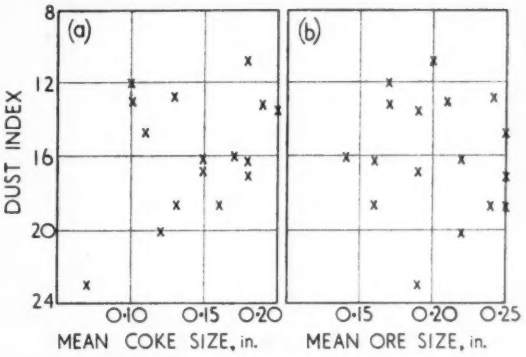

Fig. 4—Random effect of size of materials on dust index

Table VI

PROPERTIES OF SINTERS AND RAW MATERIALS RECORDED IN DETERMINING FLUCTUATIONS DURING PRODUCTION

Serial and Trial Nos.	Date	Raw Materials										Sinter Assessment	
		Size Grading		Feed Rates			Analysis				Effective Carbon, %		
		+½ in., %	−½ in., %	Coke, %	Flue Dust, %	Return Sinter, %	C, %	Fe, %	Loss on Ignition, %	H_2O, %		Dust Index	−⅛ in. as made, %
7/1	4/ 7/47	20·2	54·6	6·5	11·8	...	8·3	32·4	13·2	15·8	7·34	16·2	13·6
2	10/ 7/47	29·5	31·2	6·9	14·4	...	5·2	34·0	15·4	18·0	6·01	18·6	11·0
3	10/ 7/47	25·1	34·0	7·0	10·3	...	4·9	31·2	17·3	17·5	5·86	18·5	17·8
4	10/ 7/47	17·2	40·7	6·2	11·6	...	6·9	31·6	15·6	19·2	6·53	16·1	23·5
5	11/ 7/47	24·0	39·3	7·1	12·4	...	8·0	32·4	14·3	16·7	7·51	16·8	13·9
6	25/ 7/47	19·0	43·5	6·6	17·3	...	7·6	34·2	11·1	17·0	7·08	12·8	9·2
7	25/ 7/47	27·5	34·7	5·9	11·8	...	6·3	32·0	15·7	16·5	6·09	20·1	23·3
8	1/ 8/47	15·7	47·5	6·7	13·1	...	7·1	33·6	13·6	17·8	6·92	13·2	14·1
9	1/ 8/47	12·4	52·6	6·8	8·9	...	8·1	32·8	12·5	15·0	7·42	13·5	10·5
10	1/ 8/47	21·1	41·9	8·5	12·2	...	7·9	32·0	15·7	15·7	8·19	10·8	10·1
11	14/10/47	16·3	49·3	7·6	7·8	...	...	...	...	14·8	...	15·5	10·7
12	15/10/47	20·4	43·9	7·0	9·5	...	6·9	34·0	14·0	14·7	6·93	12·0	8·1
13	16/10/47	16·0	47·3	5·8	11·5	...	4·8	34·6	13·1	15·5	5·22	16·9	9·7
14	22/10/47	13·8	49·7	6·8	9·3	...	5·0	34·4	13·8	14·5	5·81	18·6	13·2
15	23/10/47	15·2	54·9	7·3	14·4	...	6·2	34·0	14·2	14·5	6·67	14·7	13·1
16	23/10/47	20·2	45·5	7·7	10·8	...	6·1	32·6	17·1	14·5	6·83	13·0	8·1
17	29/10/47	18·0	48·3	4·4	5·9	...	3·6	37·2	13·4	14·0	3·97	22·8	28·1
8/1	5/ 7/48	17·2	44·6	6·5	13·9	27·6	8·5	34·6	8·4	15·7	7·43	14·5	7·0
2	6/ 7/48	18·2	41·2	7·7	8·1	26·6	7·2	32·2	12·4	14·2	7·44	14·5	7·7
3	6/ 7/48	16·3	39·5	7·7	11·5	27·5	6·8	31·4	14·2	14·7	7·21	14·6	6·1
4	7/ 7/48	12·1	48·3	5·9	9·2	6·4	6·0	33·2	14·8	15·5	5·95	16·7	9·0
5	7/ 7/48	19·4	38·0	7·6	7·4	9·3	6·3	33·0	15·1	16·9	6·89	17·0	11·0
6	8/ 7/48	12·1	47·9	6·5	14·6	14·1	6·6	32·6	13·1	13·3	6·55	15·9	9·1
7	8/ 7/48	14·3	41·7	6·1	10·9	6·1	6·2	33·8	14·0	15·4	6·15	16·0	6·6
8	9/ 7/48	15·6	46·6	5·6	11·4	10·7	7·6	33·6	10·7	14·7	6·50	15·2	4·4
9	9/ 7/48	14·6	47·1	6·4	8·7	10·6	6·0	33·2	12·7	15·5	6·20	16·3	13·8
10	10/ 7/49	11·2	51·0	5·1	9·5	10·1	5·4	33·0	13·7	14·4	5·24	24·2	18·9

Serial 7 : No measurements of return sinter. Trials 7/2 to 7/4, return-sinter feed interrupted
Serial 8 : With measurements of return sinter. Trial 7/7, ignition not uniform

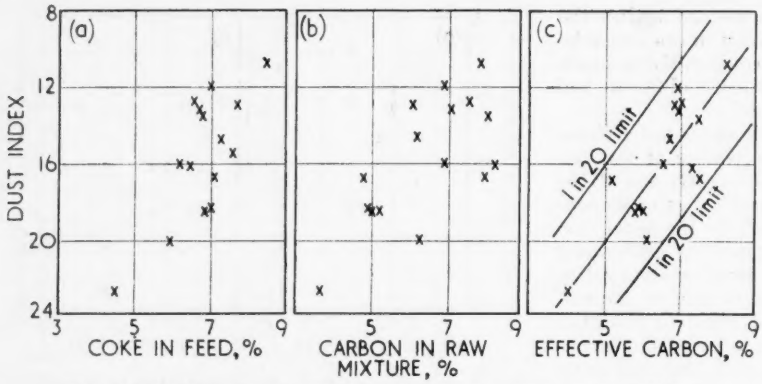

Fig. 5—Significance of effect of coke and carbon on dust index

in sinter quality could be attributed to control during trial of a particular variable or to uncontrolled variation of some other factor in the plant, but no fundamental significance is attached to it.

Summary of Statistical Analysis—The plots of dust index against the carbon factors mentioned are shown in Fig. 5. The relation involving the effective carbon is more significant than the relation to coke content, the correlation coefficients being 0·81 and 0·71 respectively. The significance of the effective-carbon relationship is better than the 0·001 level. The further observations on normal production, described later, confirmed the validity of the relationship between effective carbon content and the dust index. By calculation of approximate 5% confidence limits this graph could be used to determine the significance of any variation of sinter quality brought about by particular changes in the plant operation. When the results are set out in this way and the lines corresponding to the confidence limits are inserted, a form of control chart is obtained. This can be used to determine whether there has been any significant change in sinter quality resulting from a predetermined variation of raw materials.

When the search was made for the factors controlling the $-\frac{1}{8}$-in. dust content of the sinter as made (which does not necessarily vary in a regular manner with the dust index), it was found that the coke content rather than the effective carbon content gave the best relation. This is illustrated in Fig. 6, the correlation coefficient being 0·745, indicating a 0·001 level of significance. It was further attempted to find the possible causes for the deviations of dust content from those predicted, by this relation. Deviations were plotted against the total-volatiles/total-iron ratio and appeared to give a fair relation, but this was not confirmed by statistical analysis. It is rather unexpected that a change of this ratio by about 30% should not be readily detected. This suggests that the critical phase of the sintering process takes place at temperatures much higher than those of calcination.

The relevance of the two assessment figures merits discussion at this juncture. The method of determination of the dust index practically ensures, for sinters from home ores at least, that only the sintered fraction contributes to the assessment, and the figure obtained is not greatly dependent on deviations from completeness of sintering, provided that these are small. They are, of course, detected by the initial size-analysis test. A high figure for the $-\frac{1}{8}$-in. sinter content as made can be caused either by the complete sintering of a mixture low in carbon or by the incomplete sintering of a slow-burning mixture with high carbon content, but the dust index for such sinters will differ. A low dust index indicates that the sinter bond is able to resist breakdown during subsequent handling. There is a limit to the improvement of strength by the increase of carbon content, for although increasing the carbon content of the mixture improves the sinter quality, it also decreases the rate of sintering. With very high carbon contents and normal production conditions there may be a considerable completely unsintered fraction present when the pallets are discharged, revealed as a larger figure for percentage $-\frac{1}{8}$ in. in the sinter as made. This figure will give this indication with greater reliability if it relates to sinter sampled from the pallet; samples taken at a later stage have passed over the return-fines screens.

Series 8. Extension of Trials to Include Measurement of Return Fines

In the preceding trials no measurements were made of the percentage of return fines in the raw materials. Plant alterations were carried out by Messrs. Stewarts and Lloyds, Ltd., early in 1948, after which it was possible to measure the input of return fines as for the other raw materials. A further series of ten observations was then made on normal production sinters. The reinforcement of the Corby team by members of the staff of Messrs. Stewarts and Lloyds, Ltd., enabled measurements to be made simul-

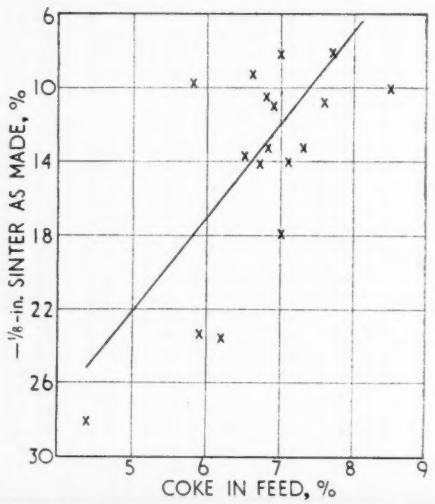

Fig. 6—Relation between coke content and dust in sinter

taneously and continuously until after the mixture on the bed was sampled. In this way a more accurate estimate of the composition of the materials in the selected pallet could be made. Samples of ore, coke, return fines, and the mixed materials were taken for size analysis and the sinter was sampled and tested as in the earlier trials.

The summarized results are included in Table VI (Series 8) and in Fig. 7, where the dust index of each sinter is plotted against the effective carbon content of the raw mixture. The results agree well with those obtained in the previous series of trials, and confirm that the physical quality of the sinter is primarily dependent on this carbon content.

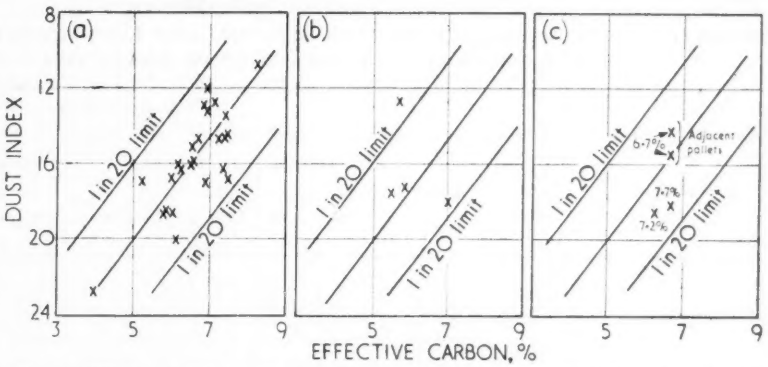

Fig. 8—Effects of interrupted suction and limestone addition. (*a*) Normal operation, (*b*) interrupted suction, (*c*) limestone addition (the two plots showing the same value refer to adjacent pallets). Significance lines for normal operation are included in each graph to show the non-significant effect of variables considered

The range of return fines during these experiments was 6–28%; within this range there is no direct evidence of any dependency of sinter quality on the content of return fines. Sinters 8/1, 8/2, and 8/3, with over 25% return fines, have dust indices equal to those predicted for the effective carbon content, whilst the other sinters with return-fines contents of 6–15% show random arrangements. The sinters with over 25% return fines had no patches of unsintered material: this may have been attributable to the better and more even bed permeability imparted by the returned fine material. It was recognized at the time of these trials that the range of percentage of return fines was rather restricted, and this deficiency has become more apparent from the comparative study of other work.

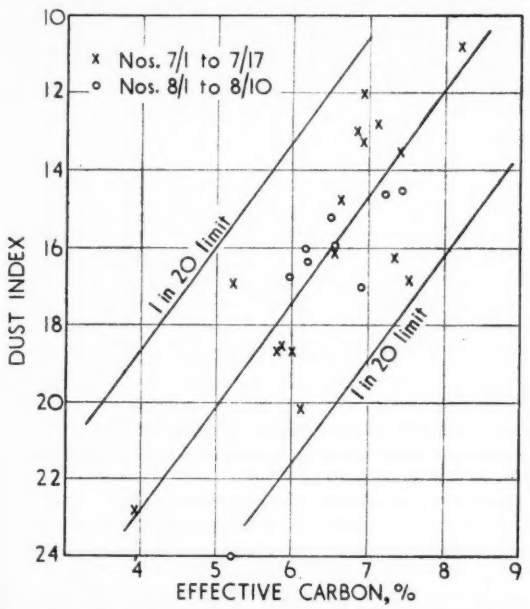

Fig. 7—Relation between effective carbon and dust index

OTHER TRIALS CARRIED OUT WITHOUT SPECIAL PREPARATION OF RAW MATERIALS (SERIES 9)

A few trials were carried out previous to the installation of the hammer mill, in which the information from Series 7 was used in the presentation of the results. Empirical study was made of the effect of interrupting the suction by closing alternate windboxes, and of the effect of adding limestone to the raw materials. The same input and output sampling operations and the same assessments of sinter quality were carried out as in previous series of trials.

In the trials of interrupted suction, normal sintering conditions were maintained except that alternate windboxes were blanked off by sliding plates in the offtakes. This was done to follow up, in full-scale practice, a suggestion from laboratory experimental results that the heterogeneity of the sinter might thereby be reduced. If uneven sintering takes place because of variation in the distribution of coke in the bed, resulting in high temperatures and slagging in the coke-rich regions, and low temperatures and undersintering elsewhere, an interruption of the draught might allow a more even temperature distribution throughout the bed to take place and thus give more uniform sinter.

In the trials with additional limestone, about 7% of coarsely graded limestone was fed on to the raw-material belt through one of the feed bins, no other alteration being made to plant operation. The deleterious effect of this coarse grading of the limestone was easily distinguishable on the sinter produced, pieces of calcined limestone being dispersed throughout the bed and forming sources of dust.

The results are set out in Table VII, and are plotted in Fig. 8, where the assessment of quality can be compared with the range of assessed values predicted from the effective carbon content for sinters produced without departure from normal conditions. It will be seen that only in one case of interrupted suction and in no case of added limestone does the physical

Table VII

STUDY OF EFFECTS OF INTERRUPTED SUCTION AND LIME ADDITION BY COMPARISON WITH SINTER PROPERTIES ASSESSED FROM ANALYSIS OF FLUCTUATIONS

Trials			Raw Materials								Sinter Assessment	
Conditions	Serial and Trial Nos.	Date	Size Grading		Feed Rates			Analysis		Effective Carbon, %		
			+½ in., %	−½ in., %	Coke, %	Flue Dust, %	Lime, %	C, %	H_2O, %		Dust Index	−⅛ in. as made, %
With slides	9/1	2/10/47	15·5	47·0	6·3	9·8	...	5·2	13·5	5·74	12·7	7·1
	2	2/10/47	14·8	45·2	6·0	12·2	...	5·7	13·6	5·85	17·2	9·6
	3	7/10/47	14·1	43·0	7·1	4·5	...	5·9	13·4	6·98	18·0	12·1
	4	7/10/47	15·3	47·7	6·1	9·1	...	5·0	14·7	5·51	17·5	10·4
With addition of lime	5	1/12/47	13·1	50·8	7·4	7·0	7·7	5·9	14·1	6·60	18·3	11·9
	6	1/12/47	15·4	50·2	7·4	4·8	7·2	5·3	18·8	6·26	18·6	9·4
Two adjacent pallets with lime addition	7	5/12/47	13·7	43·0	6·7	13·7	6·7	6·6	13·5	6·66	15·4	7·4
	8	5/12/47	13·7	43·0	6·7	13·7	6·7	6·6	13·5	6·66	14·2	8·0

quality of sinter differ significantly from that predicted from a knowledge of the rate of feed of coke and the carbon content of the mixed raw materials. The restricted evidence of the trials of this series indicate that the operations studied have no discernible effect on the quality of sinter as long as other variables give rise to significant effects.

TRIALS USING RAW MATERIALS TREATED BY THE HAMMER MILL (SERIES 10)

As indicated in Fig. 2, the installation of the hammer mill for preparation of raw materials free from large fragments had been carried out during the period in which all the previous trials (except Series 8) took place. When the hammer mill was first installed it was found necessary to carry out some mechanical development, but the machine could be used for experimental work of limited duration. The installation and development of the machine are described in Appendices I and II.

During the early development of the hammer mill the duration of each period of operation was governed by the nature of the particular development trials or of the method of hammer-mill operation being investigated. Although the difficulties experienced at first in crushing the wet and sticky ore caused much interruption, there were times (when new hammers were in use) when operation was obtained for over an hour. This was just long enough to make assessments of sinter quality and to relate these results to plant conditions. Although changes of conditions were mainly brought about in attempts to improve hammer-mill performance, some were relevant to questions under investigation as part of the main programme.

General Observations on the Effect of Treatment by the Hammer Mill

The position of the hammer mill (*see* Appendix I) was such that the feed of raw materials was diverted into the mill without stopping the sinter machine. The only delay involved in commencing to sinter the crushed mixture was the time taken for the material to be brought up by the bucket elevator. This caused some two or three pallets to be incompletely filled and it was therefore easy to make a visual comparison between sinters from the normal and crushed mixtures.

The mixture from the mill appeared to be completely homogeneous, but because of the low headroom below the mill the air blast from the rotor caused the materials to be firmly impacted on the delivery conveyor, and when the ore was sticky, slabs of hard mixed materials were produced which were not completely broken up before entering the trommel mixer. This effect was observed only when an open input chute was fitted to the hammer mill, permitting the free circulation of air and causing conditions such that the material was projected on to the belt. After passing through the mixer, small balls of compacted fines were still present. These did not sinter well,

Table VIII

SIZE ANALYSES OF MIXED RAW MATERIALS BEFORE AND AFTER HAMMER MILL

	Size Analysis of Mixed Raw Materials, %					
	+½ in.	+¼ in.	+⅛ in.	+⅛ in.	+1/36 in.	−1/36 in.
Before hammer mill	13·2	33·7	44·4	67·2	74·2	35·8
After hammer mill	0·3	4·5	12·6	30·8	35·3	64·7

and broke down to dust during discharge of the sinter from the strand.

The results given in Table VIII show typical size analyses of the mixed materials before and after crushing, and it may be seen that there is a great reduction in the $+\frac{1}{8}$-in. fraction and that the percentage of fines below $\frac{1}{36}$ in. is more than doubled.

Influence of Preparation by Hammer Mill Upon the Sintering Process

When the hammer mill was used for the first time the influence on the sintering process and the quality of the sinter was immediate and very striking. The conditions had not been set specially but were evidently favourable for the change of size analysis and degree of mixing of the materials. There was naturally much less segregation at the swinging spout, and the layering of the raw material on the strand was quite uniform. The condition of the sinter at the discharge end, and its behaviour on leaving the strand, differed entirely from the normal operation. The whole depth of the bed was completely sintered and the product broke away on discharge in large masses. There was a complete change in appearance from the characteristic uneven texture and colour of the sinter from unprepared materials to a uniform and completely agglomerated mass from which calcined material had almost entirely disappeared. The sinter broke up to very clean large fragments on the discharge screen giving rise to much less dust above the discharge than had ever previously been observed. The appearance and apparent properties of the sinter were most satisfactory, and the difference from the normal product discharged from the plant was very marked.

In normal practice, the shrinkage of untreated raw material on sintering was about 1 in., or 10% of the height deposited on the strand, and calcined ore fragments were always present on the surface of the sinter. When the hammer mill was used the shrinkage was increased to about 3 in., or 30%, becoming appreciable about halfway along the bed. The surface then had an undulating appearance, and there was much less unsintered material. The hammer-milled mixture was, however, not very permeable, and if the feed of the return fines was interrupted the sintering conditions deteriorated rapidly.

Observations were first made on the effect of crushing the raw mixture normally fed to the sinter plant, and measurements were made similar to those in the normal-production trials previously described. Owing to the very rapid wearing of the original hammers, crushing could be carried out for only about an hour, and a disadvantage had therefore sometimes to be suffered in that the bed was not full of crushed mixture. There was thus the possibility that with the lower permeability of the crushed mixture the quantity of air passing might have been less than normal. A further disadvantage was that the return fines added to the mixture were produced from ordinary sinter, and some calcined ore particles were thus unavoidably introduced into the prepared materials.

The first assessments attempted were direct comparisons of the sinters produced under otherwise identical conditions from crushed and normal raw materials, by the sampling of sinter from nearly

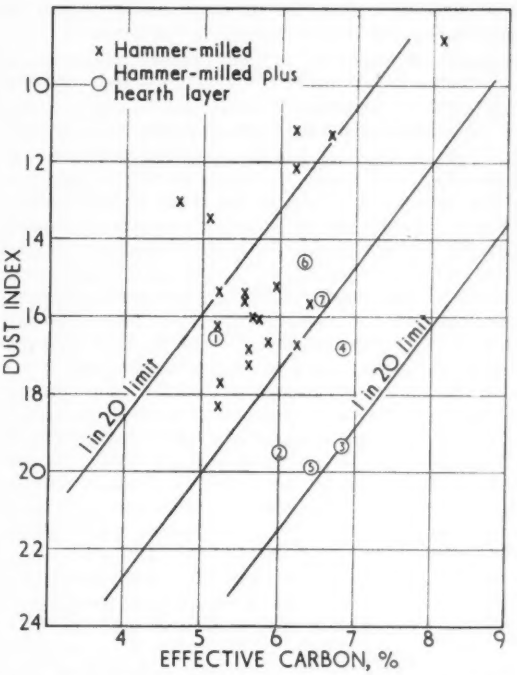

Fig. 9—Results for hammer-milled burden. The numbers refer to trials in Series 11 (Table X). Significance lines for uncrushed burden included for reference

adjacent pallets filled with crushed and uncrushed mixture, respectively. This method was not very satisfactory, because with the change-over from the crushed to the uncrushed mixture some time elapsed before the mixer had completely ejected the crushed material, and this of necessity limited the closeness within which the pallets could be selected. During the interim period the feed rates of the raw materials might have changed, and one of the pallets had a longer time on the bed owing to the time taken to remove the first pallet. In consequence the method finally adopted was to remove a single pallet containing sinter produced from the crushed mixture and to assess the effect on sinter quality by reference to the graph of dust index against sinter quality, obtained from results on normal production. From this, any change of sinter quality owing to preparation of materials was observed.

The assessment methods used were as described for the previous trials, but instead of ore and coke samples, specimens of the mixed raw materials before and after crushing were taken for size analysis. The results of assessments are included in Table IX.

The sinter quality as measured by the dust index shows improvement as compared with sinter produced from an untreated mixture. This can be seen from Fig. 9, where all the points fall on the 'good' side of the relationship found for normal production sinter.

It can be concluded, both from the visual observations and the quality indices of these sinters, that the treatment of the raw materials by the hammer mill produces a better and more homogeneous sinter, and

it is considered that the intimate mixing given by the hammer mill has considerable influence.

Influence of Other Plant and Process Variables on Sintering of Material Treated by the Hammer Mill

After these preliminary trials had established that the sinter produced from the hammer-milled materials could be of superior quality, a study was made of the influence of some variations in the composition of the raw mixture and in the plant operating conditions. These trials were carried out simultaneously with the continuing development of the mill. During most of these experiments the normal feed rates of the raw materials were unaltered but were, of course, observed ; in the experiments with high flue-dust contents adjustments were made at the feed tables to control the percentages of coke and flue dust.

In the first trials carried out at the same time as the hammer-mill development, examination was made of the effect on sinter quality of (i) high percentages of flue dust in the raw materials, (ii) control of size and admixture of return sinter by feeding through the hammer mill, (iii) reduction of suction by control of the fan speed, and (iv) reduction of added water. The results of the trials are plotted in Fig. 10.

(i) *Use of High Percentages of Flue Dust*—Difficulties when attempts were made to use high proportions (20% or more) of flue dust in the raw materials have sometimes been reported from a number of sinter plants. The sinter produced was frequently dusty, and it was suggested that this was due to the ease with which the carbon in the flue dust could be readily ignited and burnt without contributing to the sintering process. During the development of the hammer mill, trials were carried out in which high percentages of flue dust were used in attempts to avoid choking of the machine. At the same time, observations were made to determine whether the improved mixing of materials in the hammer mill rendered the carbon in the flue dust effective.

Four experiments were carried out, using flue-dust contents of 15%, 25%, 36%, and 42%, respectively. The results clearly showed that, provided that the flue dust was properly incorporated in the mix, the full advantage of the flue-dust carbon content could be utilized and a good strong sinter produced with only a small increase in the dust as made. The effect of the flue-dust carbon was well illustrated in the last two of the trials mentioned. When the experiment with 36% of flue dust was carried out the feed rate of other materials had to be reduced, but for practical reasons it was found impossible to reduce the coke rate below 7·3% ; a very hard sinter was produced, but owing to the excessive carbon content of the mix the pallet was burnt only half through.

Table IX

ASSESSMENTS OF SINTERS FROM MATERIALS TREATED BY HAMMER MILL WITHOUT SEPARATE HEARTH LAYER AND WITH EFFECTS OF PROCESS VARIABLES STUDIED DURING DEVELOPMENT OF HAMMER MILL

Conditions, Variables Studied, or Occasion of Trial	Serial and Trial Nos.	Date	Raw Materials								Sinter Assessment	
			Size Grading		Feed Rates			Analysis		Effective Carbon %		
			+½ in., %	−½ in., %	Coke, %	Flue Dust, %	Return Sinter, %	C, %	H_2O, %		Dust Index	−½ in. asmade %
First sinter from hammer mill	10/1	7/11/47	...	...	...	...	...	5·7	14·3	...	18·0	7·9
First assessment from hammer mill	2	10/11/47	4·8	65·8	6·2	10·8	...	4·1	13·6	5·06	13·4	4·2
Sinter passed through hammer mill	3	12/11/47	4·1	60·3	5·6	16·5	20†	4·8	13·0	5·20	15·3	5·3
Hammer mill operative	4	21/1/48	1·6	73·8	4·7	8·0	...	5·8	13·7	5·23	17·7	7·7
	5	21/1/48	1·5	78·1	6·5	9·3	...	5·5	14·1	5·96	15·2	6·1
	6	27/1/48	0·4	80·2	...	...	...	5·7	14·0	...	17·4	6·5
Crushed. Variation of flue dust. Six pallets apart	7	17/2/48	3·4	67·7	6·4	14·9	...	5·4	13·0	5·85	16·6	9·5
	8	17/2/48	4·8	67·5	6·0	25·0	...	5·1	12·5	5·53	15·4	9·1
	9	25/2/48	2·8	75·4	5·6	20·2	14	5·5	13·0	5·52	15·6	7·8
Uncrushed*	10	25/2/48	11·0	54·2	5·6	20·2	14	5·3	12·0	5·39	16·3	7·2
Crushed (high flue dust)	11	4/3/48	0·3	87·8	7·3	36·4	...	9·0	17·0	8·12	8·8	12·1
Crushed	12	10/3/48	...	...	5·6	10·8	...	5·5	15·0	5·57	16·8	5·6
Crushed	13	12/3/48	5·9	71·3	7·3	12·0	...	5·6	14·2	6·38	15·6	7·5
Crushed	14	15/3/48	3·2	78·1	6·2	16·7	...	5·0	15·0	5·58	17·2	6·6
Crushed (high flue dust)	15	23/3/48	1·0	84·6	3·3	42·2	...	6·7	16·7	4·68	13·0	11·9
Crushed	16	6/4/48	5·4	73·9	7·3	12·1	...	4·4	12·8	5·66	16·0	9·2
Uncrushed*	17	6/4/48	20·1	41·5	6·0	17·2	...	4·7	9·2	5·31	14·0	8·9
Reduced suction	18	14/4/48	2·0	82·1	5·9	21·7	7·5	5·5	13·1	5·70	16·1	9·3
Sinter through hammer mill	19	23/4/48	0·3	86·7	6·6	13·6	22†	5·8	13·9	6·19	12·1	4·1
Continuous hammer-mill trials	20	6/10/48	8·5	60·3	6·7	13·6	...	5·8	12·1	6·23	16·7	5·6
	21	6/10/48	9·6	62·1	7·1	9·2	...	4·4	11·0	5·17	16·2	9·6

* Trials 10/10 and 10/17 carried out for standardization

† Figures refer to sinter fed through hammer mill ; no separate observation on normal return sinter

The trial with 42% of flue dust was carried out under better conditions, and the coke rate was lowered to 3·3%. The sinter in this case was good, and the bed was completely burnt through.

(ii) *Simultaneous Crushing of Raw Materials and Return Sinter*—Two trials were carried out in which about 20% of return sinter was added to the raw mixture before crushing; this was done primarily for trial of the use of return fines in the mixture in order to reduce the choking of the hammer mill, but the trials are also of interest in connection with the effect of mixing and the size of the return-fines addition.

The size analysis of the raw mixture during these tests showed only 0·3% of + ⅛-in. material, and the return fines were fully incorporated in the mix. No further additions were made, and the bed was fully sintered, demonstrating that crushed sinter is effective in producing a permeable bed. The sinter was strong and free from dust as made, having only about 5% below ⅛ in., and the dust index was low; in fact, under these conditions the quality of the sinter was better than under any others explored, but wear on the hammer tips was very severe.

(iii) *Reduced Suction*—One trial using reduced suction was carried out. The indicated fan suction was reduced from 14 in. W.G. to 4–8 in. W.G., the measured suctions on the first windbox being 14½ in. W.G. and 7–8½ in. W.G. Unfortunately, owing to other causes, the selected pallet had to remain on suction for 45 min. Assessment of the sinter indicated a quality similar to that of sinter from materials treated in the hammer mill and sintered with normal suction; only a very small amount of unsintered material remained in the product.

(iv) *Reduction of Water Content*—In experiments to determine the effect of decreasing the added water, raw materials with normal water content were first sintered to establish standard conditions, after which all water additions to the mixture were cut off. Comparison of the physical properties of the sinters showed no significant variation; both were completely sintered and some slagging had taken place. The sinters produced were, however, superior to most of those previously obtained from a hammer-milled burden. The effective carbon in both cases was high, the materials with reduced water content having a slightly higher effective carbon than the normal. The results are included in Table X (Serial No. 11/7).

FINAL TRIALS FOLLOWING COMPLETION OF EXPERIMENTAL ADDITIONS TO PLANT (SERIES 11)

The last item of experimental equipment to be developed was that designed for the separate deposition of a hearth layer of sinter of controlled size grading and uniform depth (*see* Appendix I). By the time this equipment was installed the hammer mill had also been developed sufficiently to provide an uninterrupted feed of prepared raw materials. The trials carried out in the final series had as their objects (*a*) the investigation of the effect of the separate hearth layer itself, and (*b*) the execution of experiments, under conditions as nearly controlled as possible, to determine the effects of a small number of variables not already investigated adequately, namely, the maximum possible water content in the raw mixture, reduced suction (confirmatory trials), and reduction of effectiveness of ignition when maximum water contents were investigated.

Owing to constructional features of the equipment as first erected, a hearth layer of 2–3 in. in depth had to be used, although this was greater than necessary. Subsequently it was possible to reduce this to 1½–2½ in., and a further reduction would have been preferable. Return fines sized 100% + ⅜ in. were used.

(a) Effect of Separate Deposition of Hearth Layer

During the first trials with the hammer-milled mixture it was noticeable that where large gaps in the grate bars occurred, particularly at the edges of the pallet, the fine material was sucked into the windbox, leaving holes in the bed. When using the crushed material in conjunction with the hearth layer there was a complete absence of these defects. The

Table X

ASSESSMENTS OF SINTERS FROM HAMMER-MILL-TREATED MATERIALS, WITH SEPARATE HEARTH LAYER, AND INVESTIGATION OF EFFECTS OF OTHER PROCESS VARIABLES

Trials			Raw Materials							Sinter Assessment	
Variables Studied	Serial and Trial Nos.	Date	Size Grading		Feed Rates		Analysis		Effective Carbon %	Dust Index	
			+ ½ in., %	− ½ in., %	Coke, %	Flue Dust, %	C, %	H_2O, %			− ½ in. as made %
Standard	11/1	2/12/48	4·7	71·9	5·5	21·2	5·7	14·5	5·65	16·5	11·1
Standard	2	10/12/48	4·6	72·3	6·5	11·9	5·6	15·2	6·03	19·5	11·1
High water content*	3 (a)	15/12/48	5·0	68·2	6·9	12·5	6·8	16·3	6·85	19·3	13·3
High water content†	3 (b)	15/12/48	5·0	68·2	6·9	12·5	6·8	16·3	6·85	16·8	8·7
Standard	4	28/1/49	3·5	72·0	7·7	17·5	5·4	11·3	6·44	19·9	10·4
Standard	5	1/2/49	4·1	72·4	6·8	11·9	5·9	12·3	6·33	14·6	7·2
Reduced suction	6	17/2/49	5·2	63·8	7·3	13·6	5·9	13·8	6·56	15·6	11·0
Standard‡	7 (a)	30/6/49	2·7	67·9	5·7	14·3	6·7	14·8	6·17	11·1	8·3
Low water content‡	7 (b)	30/6/49	4·5	73·0	7·2	16·5	6·2	13·3	6·67	11·3	7·9

* Sample taken from poorly ignited area † Sample taken from well-ignited area ‡ No hearth layer used

hearth layer prevented fines dropping through the grate bars and had a decided effect in preventing sinter sticking to the pallets. During these trials the feed of raw materials to the bed was not reduced, and in consequence the speed of the machine had to be increased, but sintering was nevertheless complete, and there was little tendency for the hearth layer to be incorporated with the sinter produced. The sinters produced with a hearth layer of 1–2 in. gave a better dust index than those with a hearth layer of 2–3 in., but, considering the whole range of results of this series of trials, the use of the hearth layer is not shown to affect the quality of the sinter directly. In fact, under the conditions of the trials, the dust index for sinters prepared when a separate hearth layer is used is higher than for corresponding sinter obtained without the separate hearth layer. This is readily understood, and is a consequence of the imperfect experimental equipment. Difficulties elaborated in Appendix I necessitated the formation of the hearth layer from return sinter containing much calcined ore, obtained in previous normal operation. The presence of this offset the improvement obtained from the hammer-mill treatment, since the sample taken from the pallet included the hearth-layer material. Allowance must be made for this in predicting the operation of a fully developed scheme for continuous running, and such allowance indicates that the separate hearth layer permits high quality to be maintained.

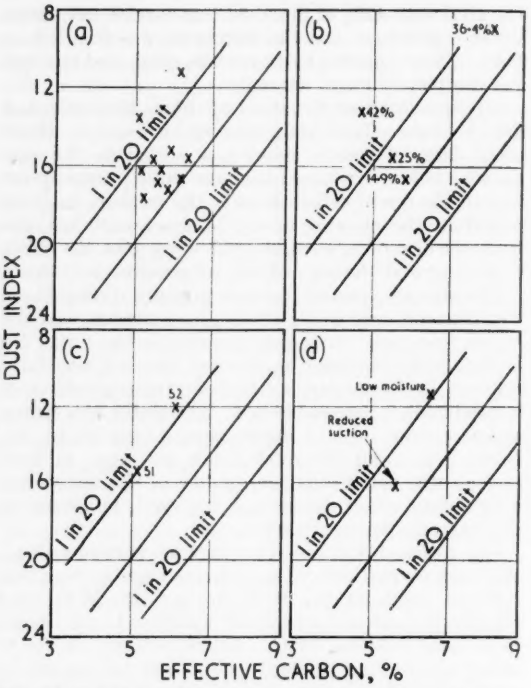

Fig. 10—Results for hammer-milled burden. (*a*) Normal mixture, (*b*) with high flue-dust content, (*c*) with return fines through hammer mill, (*d*) with low moisture and with reduced suction. Significance lines for uncrushed burden are included in each graph for reference

(b) Investigation of Effect of Other Factors after Completion of Plant Additions

Maximum Possible Water Content in Raw Mixture—To investigate the maximum possible water content in the raw mixture, the water addition was increased progressively until ignition of the strand was seriously affected, this being indicated by the appearance of a rough unsintered surface of the material leaving the ignition hood. The pallet selected for analysis was unevenly ignited, half of the top surface being loose material. The pallet sample was therefore split into two and the portions assessed separately. In the well-ignited portion with well-sintered top surface the percentage of $-\frac{1}{8}$-in. product was low, and the sinter had properties similar to those of the sinters produced from hammer-milled material with normal water contents. In the portion with top surface indicating

Table XI

OBSERVATIONS ON EFFECTS OF VARIATION OF SUCTION

Suction, in. W.G.			Sintering Time, min.	Condition of Sinter
Start of Bed	Halfway Along Bed	End of Bed		
10	12, rising to 16	17	16	Sintered through
17	18½	19½	16	Sintered through ; hot on bottom
18½	20, falling to 10	10	15	Sinter hot ; not burnt through
10	10	10	24	Sintered through ; hot on bottom ; possibly denser
10	10, rising to 20	20	...	Sintered through ; hot on bottom
20	20	17½	17	Sintered through ; hot on bottom

deficient ignition the effect of this deficiency under conditions of high water content was clearly seen, there being a loose partly calcined layer about 1 in. deep on the surface, together with pockets of unsintered material at the edge. As the vertical depth from the surface increased, the quality of the sinter improved rapidly. There was a noticeable absence of friable semi-sintered adhesions of fines, normally found in sinters from pulverized material of low moisture content. The assessment showed an increase in the percentage of $-\frac{1}{8}$-in. dust and in the dust index, as was to be expected from a sinter containing a large proportion of unsintered material. The actual water content determined by subsequent analysis of the raw material was not greatly above normal, but its influence on the process was obvious. The variation through the depth of the bed indicated that an overall improvement of quality might be brought about by raising the normal water content if it were also possible to increase the effectiveness of ignition.

Confirmatory Trials of Effects of Reduced Suction—Two trials were carried out using hammer-milled materials. The first was simply a series of visual observations of the effects of progressive alterations of suction, by change of fan speed, which are set out in Table XI. It is evident that alteration of the suction within the values noted has no marked influence on the sinter produced.* There was a small layer of unsintered material at the grate bars whilst the suction was being reduced from 20 in. to 10 in., which suggests that sintering is only slightly retarded by drastic diminution in suction. The visual nature of the observations should, however, be emphasized ; at no time was there any variation that could be definitely classified as being the result of suction change.

These observations were followed by a trial to obtain a quantitative assessment. Material treated in the hammer mill was used with a separate hearth layer, and the sinter was sampled and assessed at two values of suction. The results confirmed that the effect on sinter quality was not significant.

The results of all the trials carried out with raw materials treated by the hammer mill are set out in Table X, and are shown graphically in Fig. 9, where the numbered points refer to the trials of Series 11 and the other points refer to trials of Series 10 ; the three lines inserted refer to results with unprepared material. It will be seen that all the results of Series 10 fall on the ' good ' side of the mean line. The trend of results from Series 11 does not show any significant effects of variables other than the inclusion of the hearth layer. Reference has already been made to the deleterious influence of returned sinter from previous trials on the assessments of sinter quality, but it is clear that the hearth layer did not, of itself, beneficially affect the quality of the experimental product.

* The increase in sintering time with the low suction was due to a plant stoppage.

Part II—DISCUSSION OF RESULTS AND THEIR APPLICATION TO PRACTICE

The progress of experimental work so far described was planned in relatively limited sections, corresponding to the breakdown of the sequence of trials into respective series. Although trials of each series had, of course, common features, the successive series were not always related in logical order to the questions outstanding at the commencement of the work. The results can therefore best be presented by discussion with reference to the questions, and it is possible moreover to add significance to the result by treatment according to the order of relative importance of the plant or process factor indicated by the results of the trials.

A broad indication of this order of relative importance can be given by the most general study of the results. Factors affecting sinter quality can be grouped into categories as set out below, in order of decreasing relative importance.

(1) Factors affecting the carbon content of the raw materials.

(2) Factors arising in the process of mixing, including the size of the raw materials and the design of the mixer.

(3) Factors affecting the composition of raw materials other than the carbon content, namely the return-fines content and the chemical composition of the ore.

(4) Factors directly related to the combustion stage of the process, such as the ignition efficiency and the amount and control of air drawn through the bed.

A simple statement that these factors have an influence on sinter quality does not constitute new information, nor does a purely qualitative description of such influence. The significance of the results of these trials is thought to lie mainly in the indication of the order of relative importance of the factors, and in some cases of the limits within which the magnitude of these factors can be permitted to fluctuate.

(1) CARBON CONTENT OF RAW MATERIALS

Of all the factors governing sinter quality and properties of the raw materials the most important is the effective carbon content of the mixture. If the carbon content varies, the physical properties of the sinter are immediately changed, and by no subsequent modification to operation or process is it possible to correct any deleterious influence of such a variation. In particular, a reduction of the effective carbon content below a fairly critical value leads to a complete collapse of sinter quality, a soft product with much unsintered material being obtained, as is clearly shown by the results in Part I. The converse is not necessarily true, however ; excessive carbon tends to reduce the speed of sintering and therefore, if the machine speed is not reduced to give extra sintering time, once more unsintered

material will be present in the product. However, in this case, slowing of the sinter strand can effect a control of quality, and the worst effect is thereby avoided.

Any breakdown of control of feed rates on a plant sintering home-ore fines will very shortly lead to an unacceptable departure from the minimum standards of sinter quality. This is particularly true of the coke or flue-dust feed, which control carbon content directly; when it was possible to maintain controlled conditions in these trials, and the proportions of the raw materials were held constant and correct, good sinter was consistently obtained. If the control was insufficient the variations which ensued caused deterioration of the sinter, and a high-quality product could not be obtained even when the raw materials were temporarily of a composition which should have given good sinter. This emphasizes the importance of maintaining steady as well as correct average proportions of raw materials in the mixture.

The application of this control in practice is therefore most important and generally is a matter of correct initial plant design. The need for meticulous attention to this point has been recognized by experienced plant operators.[5] Control is effective when the proportions of raw material can be maintained indefinitely by the correct setting of feed-table conditions and when the physical conditions and uniformity of chemical composition of the burden components are satisfactory. These divisions of the control process merit individual discussion.

Feed Tables

The provision of a variable-speed control presents no difficulty, but there are materials of which the feed from a table running at a constant speed setting may be far from uniform. The problem therefore is to relate the speed of the feed table to the rate at which material is coming off the table. This difficulty becomes one of development peculiar to each set of plant conditions, and an overall solution cannot be formulated. Where the material is dry, regular, and flows freely, the open-mouth type of feed table works well, provided that the table diameter is sufficient to avoid spillage. With sticky material, however, consistent results are difficult to achieve. The accuracy of feed is dependent upon a free flow from the hopper to the table, and when this becomes indeterminate the accuracy is lost. Accordingly, the positive-gate feed table has been used for ore of this nature, but is not fully satisfactory. Provision of a more satisfactory type is an urgent and important problem of design which will require further full-scale experiment to indicate the necessary dimensions and operating data to meet individual requirements.

Raw Materials

In order to maintain satisfactory operation of the feed tables it may be necessary to exercise some control over the condition of the raw materials. If these are of the free-flowing type which feed satisfactorily through open-mouth tables, the admixture of relatively coarse extraneous fragments will not interfere with constant feeding, although the short-period accuracy of delivery will suffer a little. The open-mouth feed table possesses great practical advantage in not being permanently affected by such irregular materials, the entire elimination of which may not be practicable.

When it is necessary to depart from the open-mouth design the elimination of any irregularity in the raw materials becomes very important, and a balance must furthermore be held between the proportions of fine ore and lump ore. Greater care must be taken to avoid accidental feed of large fragments to closed-mouth tables, as this type cannot generally be self-cleaning. Fines screened at a low top size may be troublesome at the feed table because of sticking if there is excessive adherent clay. Regularity of the size distribution of raw materials and freedom from accidental admixture of large fragments are thus important aims in plant operation.

Variations of chemical compositions of raw materials and particularly of carbon content of coke and flue dust will, of course, have the same effects as variations of feed rates at the tables. Unfortunately, layout of storage and feed systems to minimize variation in chemical analysis of raw materials at the plant becomes complex and costly; the materials used for sintering are such that these variations are inevitable. The control of feed rates is therefore important, and when this is an integral feature of operation the effects of variation in analysis are easily recognized and corrected.

The techniques adopted for the determination of fluctuations of the composition and proportions of raw materials during these trials were as comprehensive as could be achieved for the experimental work. In the application of the results of the trials, questions of sampling and assessment will of course arise. It is thought that the indications from the present results are sufficiently definite that it could be regarded as an essential feature of application to evolve sampling methods applicable to the routine of any individual plant. Methods much the same as those used in experiments would be suitable for the determination of feed rates and analysis of mixed materials, but much more rapid analytical methods are needed to take full advantage of the potentialities. The sampling of the product raises difficult problems, and the methods adopted in trials may not be permissible in normal production. The use of sampling vehicles independent of normal production traffic was investigated during these trials, and although they were not satisfactorily developed even for experimental work it would appear that some such development would permit sufficiently rapid sampling and assessment of sinter for quality-control methods to be applied. Simultaneous and rapid sampling of raw materials and product, and rapid analyses and assessments, would provide the data for prediction of the sinter quality and would confirm the prediction or give clear warning to search for operational causes affecting quality of product in an otherwise unknown manner. It is probable that the rigorous application of such quality-control methods to the process would bring about a greater improvement of sinter quality and its consistent maintenance than any other change in plant, process, or operations.

(2) MIXING OF RAW MATERIALS

Mixing takes place immediately after delivery from the feed tables and effects a control on the general level of sinter quality second in importance only to that effected by constancy of the effective carbon content. At an early stage in the trials it was observed that reduction of size of raw materials alone did not necessarily improve sinter quality, and it was shown by a number of methods that there was scope for the improvement of mixing. This was confirmed when the hammer mill was installed, and the influence of combined size reduction and mixing was shown to be much greater than that of size reduction alone. It is not possible to give any general specification of method and degree of mixing necessary to obtain optimum quality of the sinter, but it may clarify the position to consider the following systems which have shown improved operation when compared with a standard open trommel mixer:

(*a*) A rotary mixer similar to the trommel but giving mixing of longer duration.

(*b*) Various types of drum mixers with a central paddle.

(*c*) The high-speed hammer mill, which reduces the size of, and mixes, the raw materials (*see* Appendix II).

(*d*) A system of hoppers devised by Messrs. Stewarts and Lloyds, Ltd., to provide adequate mixing of the raw materials, followed by induced 'balling' of the materials during discharge from the unit. This system places emphasis on the mechanical conditioning and relative coating of coarse ore with fine fragments of coke.

To specify the efficiency of mixing is not easy, but mixing is clearly related to the size analyses of the raw materials. It is, in fact, at the stage of mixing that the question of size analyses is most important.

Size Grading of Ore and Coke

The general experience of practical operators submitted at the commencement of these trials was that fines for sintering should be $-\frac{1}{2}$ in. in size and that coke breeze should be $-\frac{1}{8}$ in. Samples of home-ore sinter, as generally produced about 1946, usually contained a large number of ore fragments which were under-sintered. It seemed reasonable that the large size of the fragments was the factor primarily responsible for the failure to sinter, and from this reasoning the earliest trials were commenced. However, it was found that elimination of all $+\frac{1}{4}$-in. material from the mix did not immediately eliminate the unsintered fraction. Further evidence on the effect of ore size includes (*a*) the fact that occasionally large fragments of ore were sintered, (*b*) the apparent absence of a relation between ore size grading and sinter quality as indicated by the analysis of plant observations, (*c*) the use of the hammer mill gave a significant reduction of unsintered content, and (*d*) the later achievement, in the course of normal plant development, of a marked reduction of unsintered content following improvements to mixing and proportioning, although the ore size was up to $\frac{3}{4}$ in.

From such evidence and from other results[6] it seems clear that the sintering process does not impose a sharp upper limit on the size of ore that can be sintered. In attempting, however, to put into practice any of the indications concerning proportioning and mixing of the raw materials, it immediately becomes apparent that properly proportioned and mixed materials can be obtained only by restricting the upper limit of size for ore, and thus setting an upper limit for the size of coke.

In addition, the effects of calcination found with the majority of home ores set an upper limit to size. During the heating phase of the sintering process calcination takes place without sintering. If, because of imperfections in proportioning and mixing of materials, the sinter bed does not remain at a temperature above the calcination range for sufficient time, fragments of calcined ore remain in the finished product. This makes the product weak and friable, and it will break down to dust on handling or in the furnace.

It is difficult to specify an 'ideal' size grading for ore, or even for coke to mix with ore of a known size analysis. When the mixture has passed through the hammer mill the maximum size of ore is $\frac{3}{8}$ in. and the materials sinter completely, leaving no unsintered residue of oversize ore fragments, but this is not attained by merely eliminating oversize ore alone. As a general rule, the trials confirm that $\frac{3}{8}$ in. should be the maximum size for soft home ore. It follows therefore that in order to mix, say $\frac{1}{20}$th of the weight of coke with the ore the maximum coke size must be restricted.

The evidence on coke size confirms the views held by many operators. Observations made at an early stage showed that elimination of oversize coke ($+\frac{1}{8}$ in.) permitted more complete sintering of a coarse ore mix. In addition to this evidence there were the failures to obtain good sinter in any early trials without very fine coke and the effect of the hammer mill, observed at the later stages.

In general, trouble is noticeable when the coke size exceeds $\frac{1}{4}$ in. maximum; 100% $-\frac{1}{8}$ in. is accepted as good, and in these trials gave rise to no trouble which could be attributed to coke size. Gross departures from this size grading have the effect of concentrating the fuel into discrete small pockets, leaving material unsintered in any region remote from the coke fragments. There is no evidence that it is necessary to reduce all raw materials to below $\frac{1}{8}$ in., as has been suggested from time to time, as adequate processing of larger fragments is quite practicable provided that good mixing can be obtained.

The nature of the raw materials used makes it difficult, if not impossible, clearly to separate any evidence as to the effect of very fine material (— 100 mesh). The ore, which is the major component of the mixture, is always wet, and so discrete fines never become detached. In the very few instances where trials were carried out with dried ore the loose fine powder gave trouble because it was difficult to wet for remixing.

Flue Dust in Raw Materials

The flue dust used on the Corby plant generally contains about 30% of iron and 10% of carbon and is regarded in practice as a useful component, although experience and semi-scale[4] trials indicated that it did not sinter completely in the mixture and that increas-

ing flue dust in the raw material led to increasing dust in the sinter produced. It did, however, seem possible that if mixing were improved, more flue dust than the usual 15% could be used. Analysis of the observations made in the trials of Series 7 and 8 indicates that the flue-dust carbon does contribute to the total fuel. The trials carried out with the hammer-milled mixture confirm both the potentialities and limitations, and it can be concluded that up to 40% of flue dust can be incorporated if mixing is thorough, with full utilization of the carbon and consequent production of a strong sinter, but, even when mixed by the hammer mill a higher dust content is obtained in the sinter than when lower proportions are used.

(3) RETURN FINES AND CHEMICAL COMPOSITION OF RAW MATERIAL

Effects of Quantity, Screening Size, and Disposition of Return Fines

The plant return-fines system set limitations to the scope of experiments which could be undertaken, and conclusions from this work alone must therefore be tentative. There were, however, clear indications as follows :

(*a*) The normal variation of return-fines content, causes fluctuations in the carbon content of the raw mixture, and this in turn causes fluctuations of sinter quality. When correction is made for this effect in the analysis of the results of trials, no direct influence of return-fines content on sinter quality can be detected *for mean values of this content below* 30%.

(*b*) An increase in the maximum size of return fines improved the quality of sinter from raw materials not treated in the hammer mill. When using the hammer mill to treat the raw mixture such an increase brought some deterioration, but when the return fines were fed through the hammer mill and the whole mixture reduced in size simultaneously, the quality of the sinter was better than under any other condition studied.

(*c*) The diversion of a selected size fraction of return sinter to form a separate hearth layer and isolate the raw material from the grate bars gives several operational advantages, especially when sintering material of small size. When this is done the bed seals completely, sintering is readily brought to completion, and there is no adhesion to, or burning of, the grate bars. It is still essential, however, to maintain the content of return fines in the raw mixture and to control the carbon content. The separate hearth layer does not affect sinter quality directly.

Reference must also be made to some important results obtained quite apart from the present trials. In order to improve plant control and enable the return-fines circuit to function regularly, Messrs. Stewarts and Lloyds, Ltd., enlarged the throughput of the system by replacing a vibrator conveyor by a feed table. This also improved the precision of control, and improvement of the quality of the sinter followed this change. With simultaneous improvements in the control of size of raw materials in mixing methods a consistently high-grade sinter was produced. Work carried out for the Appleby-Frodingham Steel Co. also strongly emphasized the importance of control of return fines.[6]

The experiments carried out on separate hearth layering explored the possibilities of this modification without reference to the general question of distribution of return sinter. The separate hearth layer enables the fullest benefit to be obtained from the reduction of size of raw materials, by preventing loss through, and damage to, the grate bars. For this practice return sinter should be graded into two size ranges ; for example, $-\frac{3}{8}$ in. for admixture with the raw materials at a controlled rate and $+\frac{3}{8}$ in.–$\frac{3}{4}$ in. for feeding to the hearth at a rate sufficient to give an unbroken layer. The total of sinter available as returns and the division into the two gradings will be governed by the strength of the sinter and the layout and dimensions of the screening system. It is clear that such an arrangement has potential instabilities ; if increased strength of sinter is conferred by addition of return sinter to the new mixure the total of returned sinter is reduced and a fluctuating flow of return fines will result.

There are insufficient experimental data to indicate details of design for stable operation ; such details would have to be evolved from trials specific to one plant and practice. It is considered, however, that the provision of sufficient surge-bin capacity is essential to damp out small fluctuations, and it is also extremely important to maintain the flow rates and properties of the other raw materials as constant as possible over long periods, as only by this means can regular breakage of sinter be ensured and a constant flow of return fines obtained.

Nature of Raw Materials

Variations in the following properties of raw materials during these trials were explored :

(*a*) Carbon, ash, and moisture contents of the coke.
(*b*) Carbon content of the flue dust.
(*c*) Lime/silica ratio of the slag constituents.
(*d*) Iron content of the ore, and the state of oxidation.
(*e*) Total moisture and volatile matter in the ore.

The effects of the factors (*a*) and (*b*) have already been dealt with. The remaining three were studied both by observation of normal practice and controlled experiment. Only in the case of item (*c*) (lime/silica ratio) could an experiment of any duration have been carried out, as the other factors ((*d*) and (*e*)) are governed by conditions at the quarry face. Observation of normal operation did not indicate any effect of lime/silica ratio, and plant experiments with added lime were also inconclusive ; hence, with some reservation arising from limitations of the trials, the lime/silica ratio does not appear to be as important as the other variables controlling the proportions of raw materials. Such results are specific to Corby practice, where the slag-forming material is high and the lime/silica ratio is controlled at a predetermined figure, and these conclusions may not apply in cases where small amounts of highly siliceous or amphoteric slag constituents are present or the basicity of the slag attains extreme values.

Preliminary examination of results described in Part I gives information regarding the iron, moisture, and volatile contents which is entirely empirical. Sintering tends to demand more fuel when the volatiles are high, but this does not appear to be a factor as important as the control of effective carbon. In the earlier trials in which extreme values of ferric/ferrous ratio could be chosen there was a qualitative indication that the expected lower coke consumption with highly ferrous ores was actually achieved. The practical effect is that on a plant with a steady ore supply, fuel control can deal with variations in properties of raw materials, including the state of oxidation as well as volatile and water contents.

Water Content—The water content of the raw mixture is a factor normally under the control of the plant operator (within the limits set by inherent properties of the materials being processed). It is of practical importance and its effect is reviewed here in relation to the composition and properties of the raw material.

Semi-scale work suggests that the effect of water content on bed permeability should be easily observed, and this is qualitatively true on the large scale. However, precise assessment of the total effect on sinter quality is rendered difficult by the effect of changes of water content on the effectiveness of the carbon present. In the experiments in which extreme values of water content were achieved, the lower value proved more beneficial than the upper, but there was evidence that had the fuel been adequately controlled and ignition been fully effective the greater stability of mixing of wet material would permit more complete sintering. Thus the effects of ignition efficiency and water content are closely related, as also are permissible water content and carbon content of the raw mixture. The gradual improvement of sinter quality towards the bottom of the bed when water content was high is a significant demonstration of this.

Results from all the relevant trials have indicated that at Corby the water content is not likely to run so far out of control that the quality of the sinter falls without the cause being realized. Occasions do arise when there is an excess or deficiency of water, but these can be recognized and corrected by the plant operator in a more certain and much more rapid manner than the fluctuations in rates of flow of raw materials.

(4) CONTROL OF IGNITION AND AIR

Ignition Efficiency

Ignition is another factor in which variations and deficiencies are obvious in practice. From time to time defective ignition was encountered, and its effect could be observed by consequent reduction of sinter quality. The trial carried out to determine the effect of maximum water content formed a demonstration of the limiting conditions due to the character of the ignition. With correctly proportioned and conditioned material, however, ignition as obtained on the plant at present does not limit the attainment of high-quality sinter. With an ignition system capable of igniting material mixed with more water the permitted fluctuations of raw-material composition might be greater and the mean level of quality still be maintained or even improved.

Control of Air

The final stage of the sintering process at which it might be expected that control was possible is the suction of the combustion air through the bed of partly sintered material. In the present trials it was observed that variations of indicated suction could be brought about without obvious effect on either the sinter quality or the rate of sintering. Qualitative observations and quantitative assessments were made in the final experiments with careful control, confirming that halving the speed of the fan and the indicated suction had no clear effect on the rate of sintering or on the sinter quality.

These observations were unexpected, and their validity ought to be confirmed by further experiment at a variety of plants. If such confirmation is obtained, the implications are clearly important. If suction could be reduced without affecting quality or the rate of production of sinter, plant and production costs would be significantly decreased. The volume of air now drawn through the bed per unit weight of material sintered is in excess of the theoretical volume required for complete combustion of the carbon.

RÉSUMÉ OF CONCLUSIONS AND METHODS OF APPLICATION TO PRACTICE

In the foregoing discussion a number of conclusions have been indicated with emphasis on their importance in determining the course of application of the work to full-scale practice. It may be of value to make a brief résumé of these conclusions and, where appropriate, to suggest due means of application. In some instances the design of new types of plant will come into question, and in others any alterations involved concern only the practice and its control.

(1) Control of the carbon content of the raw materials is of first importance, and may demand attention to the mechanism of feed of raw materials, especially the stage of feeding ore, coke, and flue dust from bunkers to the belt : when such arrangements are satisfactory, observations of rates of feed and samples for analysis are taken, and should be used as a basis for an appropriate form of quality-control operation.

(2) Control of mixing and size distribution of raw materials is second only to control of carbon and cannot be effected without the proper plant. Mixing is much more efficient when dealing with material of controlled rather than random size grading, but it is not yet possible to suggest designs of equipment which will ensure uniform and complete distribution of the carbon under all conditions of operation. Such designs will therefore have to be developed to meet conditions on individual plants. For the control of size of ores with a troublesome content of sticky clay it still remains necessary to develop crushing or screening plant capable of performing indefinitely the operations of reduction of size and mixing of raw materials that were carried out for short periods in these trials.

(3) Control of proportions and composition of materials other than coke and flue dust is dependent partly on the provision of adequately controlled

and stabilized feed, particularly of return sinter, on information of the variability of the raw materials, and on the availability of data enabling a return-fines screening system to be designed. A proper proportion of return fines can then be mixed with the raw materials and a proper proportion of correct-size material returned for deposition of a separate hearth layer. These items all involve matters of design peculiar to each practice, and it is not possible to extend generalized experimental conclusions to deal with them. Data for the design and throughput of sinter screens, feed tables, and conveyors must be adequate for each plant, but once these have been incorporated in the plant, adequate control of the carbon content can make sufficient allowance for variations in the flow and composition of the raw materials.

(4) Control of ignition, water content, and air flow demands proper plant for its execution. While no criterion for ignition was set up in these trials, the good influence of effective ignition and its bearing on the acceptability of high water contents and high permeability of raw material were shown to give scope for control, but design data are again required for individual plants. It is also important to note that control of these items can do little to retrieve the effect of deficiencies in the provisions already described. The control, however, can be assisted by good instrumentation to deal with behaviour of ignition, content and distribution of water, and flow of air.

Acknowledgments

It is difficult to ensure that every assistance contributed to the work reported is adequately acknowledged, but thanks are particularly due to Messrs. Stewarts and Lloyds, Ltd., for the provision of the plant and many facilities for plant engineering, technical staff, and other technical and administrative services, and to the Directors, General Management, and Plant Managers for their great patience with and active interest in the protracted programme of work. The assistance of other Companies in the iron and steel industry, especially The Cargo Fleet Iron Co., Ltd., the Appleby-Frodingham Steel Company, Messrs. Colvilles, Ltd., Messrs. Richard Thomas and Baldwins, Ltd., The Ford Motor Co., Ltd., and John Lysaght's Scunthorpe Works, Ltd., in the supply of materials and the provision of personnel is also gratefully acknowledged. Messrs. Edgar Allen and Co., Ltd., Messrs. Wm. Jessop and Sons, Ltd., Deloro Stellite, Ltd., and the Fraser and Chalmers Engineering Works assisted greatly in the development of the hammer mill. Assistance in the trials was also given by members of the staffs of the Physics Department and other sections of the Iron Making Division of the British Iron and Steel Research Association. Mr. A. J. Langner, Mr. R. J. Ryman, and Mr. J. B. Remwich were members of the investigating team for parts of the period of the trials. The guidance in the preparation of the material for publication given by Mr. I. S. Scott-Maxwell, Mr. H. R. Pepper, and other members of the Sintering Sub-Committee, and by Mr. A. Stirling of Messrs. Stewarts and Lloyds, Ltd., is gratefully appreciated. The checking and collation of the material for publication was carried out by Mr. K. E. Jermy.

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Appendix I

DESCRIPTION OF SINTER PLANT AND EQUIPMENT INSTALLED FOR EXPERIMENTS

DESCRIPTION OF PLANT

There are three sintering units at the Corby Works of Messrs. Stewarts and Lloyds Ltd., of which the most modern (No. 3) was used for the trials. It is an independently operated single-strand Dwight-Lloyd machine with flexible control of the rate of feed of raw materials, the strand speed, and the fan suction. The general layout is shown in Fig. 1.

The raw materials are fed from seven concrete bunkers, through variable-speed feed tables of the closed-mouth type (Fig. 11), with adjustable gates. Six of these bunkers have a capacity of about 100 tons each, and are normally used so that the first three feeding the belt carry ore, the next two flue dust, and the next coke breeze ; the seventh bunker is of slightly smaller capacity and is used to feed mill scale. A total ascending-belt travel of about 500 ft., with two crossovers, carries the materials to the mixer, and the return-fines feed joins the other raw material after the last bunker. The mixer originally fitted was of the trommel type, 6 ft. in diameter by 13 ft. long, with internal helical blades and rotating at 30 r.p.m. This was later replaced by a different type, but the present trials were completed with the original mixer. Water is added before the raw materials leave the trommel, and the mixture is then conveyed a short distance to the swinging spout above the sintering strand. The leading dimensions and characteristics of the strand and its movement are as follows :

The overall dimensions are 100 ft. long by 6 ft. wide. There are 16 windboxes and 134 2 ft. by 6-ft. pallets.

The total grate area under suction is 648 sq. ft., and the strand speed can be varied from 60 in. to 100 in. per minute. The suction is provided by a 9 ft. 6-in. diameter fan run at 740 r.p.m. and consuming up to 1150 h.p. Variable-suction control is obtained by altering the fan speed through a hydraulic coupling. The maximum capacity of this fan is 150,000 cu. ft./min. at 300° F. and 24 in. W.G. suction. The ignition of the mixture is effected by a brick-lined hood fired with blast-furnace gas, coke-oven gas, or mixed gas, giving a rather turbulent flame. In the original design of the plant the sinter was discharged over an inclined static screen set at $\frac{3}{4}$ in., and the oversize material is fed to a hopper sprayed with cooling water and thence to rail wagons for dispatch. The fine sinter is fed to a conveyor belt, which also serves the suction-main dust legs and discharged originally into a small hopper and thence by a cross conveyor to the raw-materials belt.

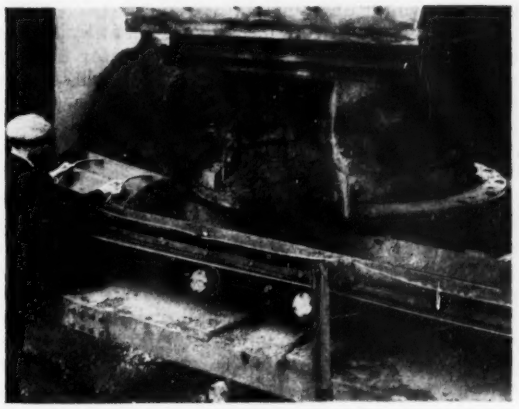


Fig. 11—Variable-speed feed table and sampling tray (for location see Fig. 1)

RAW MATERIALS

In normal practice the following raw materials are used :

ORE

Mixed fines are received from the Robbins-Messiter bedding plant. The ore is all drawn from the local ore-field and is a mixture of siliceous and carbonate stone. The average chemical analysis and size grading of the fines produced are as follows :

Chemical Analysis

Fe	SiO_2	Al_2O_3	CaO	H_2O
29·2%	8·3%	6·2%	5·7%	17%

Size Grading

− 1 in.	− ½ in.	− ¼ in.
100%	66%	32%

The ore usually contains some clay, and may thus be sticky and difficult to handle. When the percentage of such ore is high and the material is cold and wet, handling becomes particularly difficult, and even very wide clear chutes have been known to bridge and choke completely with fine ore under these conditions.

COKE BREEZE AND FLUE DUST

Coke breeze varies in water content and chemical analysis. An average size analysis is 35% + ¼-in. and 65% − ¼-in. material. The flue dust is used in a wetted condition as received from the pug mills, and is fed through one of the bunkers at the sinter plant. The carbon content of the flue dust is about 10–15%.

AUXILIARY EQUIPMENT INSTALLED FOR EXPERIMENTS

For the investigation of some of the problems experimental equipment was required in addition to the existing production plant, as follows : (*a*) Crushing or screening equipment for control of the size of raw materials, (*b*) feed tables giving uniform flow of raw materials, (*c*) plant for providing a continuous separate hearth layer of sinter sized between $\frac{3}{8}$ in. and $\frac{3}{4}$ in., and (*d*) improvements in windbox control valves.

(*a*) EQUIPMENT FOR CONTROL OF RAW-MATERIALS SIZE

Equipment for control of the size of raw materials was required owing to a number of difficulties arising from the inherent properties of the raw materials to be used. Of these the most serious was the physical nature of the ore used in normal practice. It was fully realized from the outset that the problem of control of ore size by crushing or by screening was extremely difficult, and was regarded by most manufacturers with experience of ore-preparation equipment to be almost insoluble unless the ore was previously dried, which involves an additional operation. A partial solution to this problem was the installation of a high-speed hammer mill (*see* Appendix II), which, after development work on a standard unit, was finally found practicable for use for periods of a few hours for the performance of trials. It was not possible, however, to run the unit for uninterrupted periods of several days, or on continuous full load.

As previously indicated, the coke breeze available in the earlier periods of experiment contained some fragments greater than ½ in., and considerable thought was given to means for elimination of this oversize. While it was technically feasible to prepare coke breeze as required by screening, it proved possible to carry this out only as a batch operation. Features of existing plant layout precluded the early incorporation of continuous screening; furthermore, the preparation of selected batches of 20 tons of coke was possible only at a limited rate, and rapid repetition of experiments was not readily arranged. Since it was decided at any early stage in the active preparations for these trials to install a hammer mill to treat all the raw materials, no further steps were taken to prepare coke separately.

While the trials were proceeding, a number of improvements and developments were completed by Messrs. Stewarts and Lloyds, Ltd., as part of their normal programme for the plant. Those concerning the feed of raw material and return sinter had some bearing on the present trials : towards the end of the programme the mean size of ore and coke had been somewhat reduced, the flue dust was fed through the ore-bedding plant to improve incorporation, and the layout of the return-fines conveyor system was modified. The apertures of the static screen were partly enlarged to 1½ in. The small surge-bin was eliminated, and it then became possible during later trials (Series 8 and 11) to measure the rate of feed

of return sinter and so improve the precision of the experiments. The subsequent replacement by Messrs. Stewarts and Lloyds, Ltd., of the vibrator feed for return sinter by a rotary feed table still further improved control of the feed rate, and the general level of sinter quality was thus raised.

Preparation of Raw Materials

At the outset of the work enquiries were initiated for experimental crushing or screening plant for installation by the British Iron and Steel Research Association so that the necessary preparation of raw materials could be carried out at the rate demanded by operation of the plant for full-scale experiments, involving at least 50 tons of raw mixture per hour. Manufacturers were invited to quote for their most suitable equipments, and trials were carried out to select as far as possible the most promising types for either crushing or screening. The selection of equipment for the elimination of fragments greater than about $\frac{3}{8}$ in. from the supply of the sticky Northamptonshire ore presented difficulties at least as formidable as was anticipated, and an only partial solution to the problem was actually found, after carrying out a number of trials of various alternative types of screening and crushing plant.

Screening—Although the difficulties of screening the fine ore without any drying were well known, trials were carried out to determine the proportion of $-\frac{3}{8}$-in. material which passed through a mechanically vibrated screen and the proportion of the whole feed actually passing through the screen. In such a trial using a $\frac{5}{8}$-in. screen most of the material was under $\frac{3}{8}$ in., but under relatively favourable conditions only 25% of the ore was correctly prepared. This scheme was not pursued, as an insufficient flow of prepared material would have been attained with the low efficiency of throughput.

Selection of Type of Crusher—Attempts were also made to use a number of types of crusher to reduce the ore to $\frac{3}{8}$ in. maximum fragment size. Cone crushers, various combinations of rolls, and types of hammer mill were used. Of these only the high-speed types of hammer mill showed any promise whatever. Laboratory work with a small high-speed mill (3000 r.p.m.), at about $\frac{1}{4}$ ton per hour gave promising results, and was followed by a trial of one of the larger high-speed machines available at that time, namely model 2A of the series of high-speed multi-hammer pulverizers manufactured by Messrs. Edgar Allen and Co., Ltd. It was observed that with a rotor speed of 1500 r.p.m. ore could be fed to the machine at a rate of 20 tons per hour, and in a short test about $\frac{1}{2}$ ton of ore was treated. Initially the ore had fragments up to about $\frac{7}{8}$ in., but after crushing contained about 70% of $-\frac{1}{8}$-in. material. No indication of choking was observed, in contrast to the experience with certain gyratory crushers in which the ore choked at once and no feed whatever was possible. On the basis of this rather restricted but promising investigation

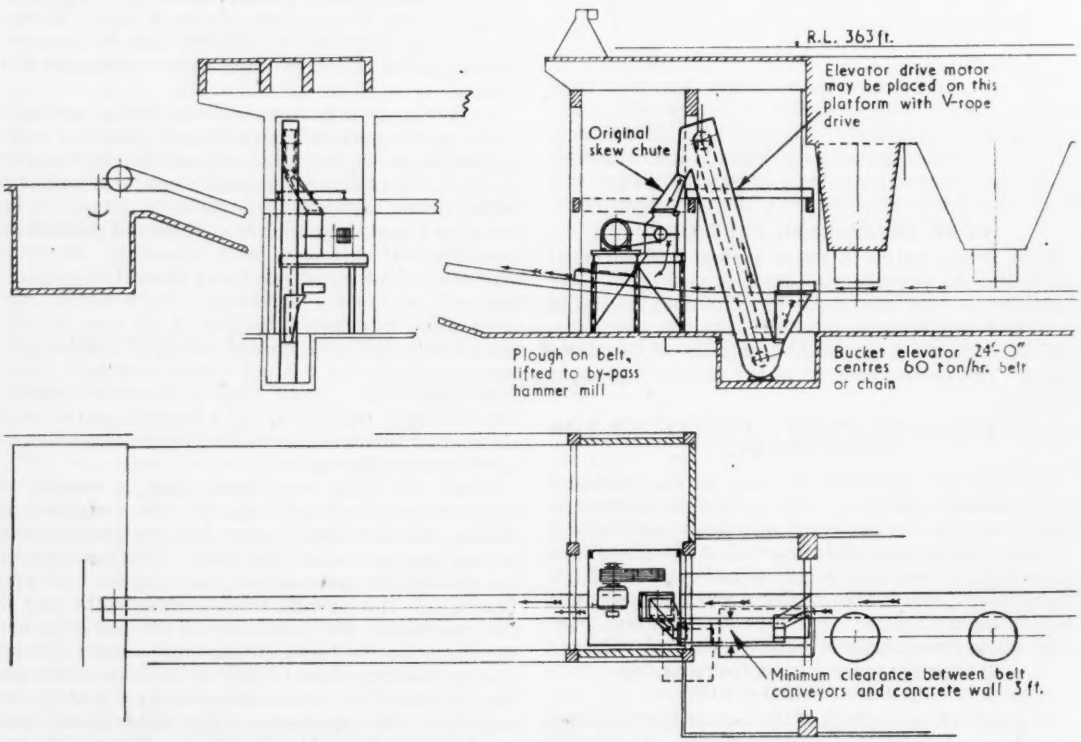

R.L. 363 ft.
Elevator drive motor may be placed on this platform with V-rope drive
Original skew chute
Plough on belt, lifted to by-pass hammer mill
Bucket elevator 24'-0" centres 60 ton/hr. belt or chain
Minimum clearance between belt conveyors and concrete wall 3 ft.

Fig. 12—Method of diverting raw materials through the hammer mill (for location *see* Fig. 1). Average raw-materials mixture 10% flue dust, 6% coke breeze, 2% mill scale, and 82% ore fines; all $-\frac{1}{4}$ in., and weighing 80 lb./cu. ft.

the larger-type mill, No. 3A, was ordered from Messrs. Edgar Allen and Co., Ltd., and was installed with the 120-h.p. drive, at the location shown in Fig. 1. The nominal capacity of this mill was 50 tons of coal per hour, and the machine was the largest available at the time with a shaft speed of 1500 r.p.m.

It was hoped that this hammer mill might be installed so that either the ore feed alone or the entire feed of raw materials could pass through the machine, but this proved impossible. In order to eliminate interference with production, it was considered essential that reversion to normal practice should be possible without delay, in the event of the hammer mill giving trouble. The method finally adopted was to fit a power-operated plough on the main feed belt which diverted the feed into the boot of a bucket elevator fitted alongside the belt (Figs. 1 and 12). The hammer mill was mounted centrally over the main feed belt so that after the material was raised by the elevator it had to be brought back to the centre-line of the hammer mill. At first an inclined chute was used, but this gave choking difficulties and was replaced by a short horizontal conveyor (Fig. 13). The material thus passed through the hammer mill and was discharged direct on to the main belt ; by raising the plough the entire elevator and crusher equipment was by-passed and normal production continued. The location is shown in Fig. 1.

Alternative schemes were considered at length. There were several possible arrangements in which existing belts would be cut and altered to give a difference of level and a direct feed through the hammer mill, but all such proposals had to be rejected because the requisite installation and operation would offer a serious hazard to continuous production, and it would be difficult to arrange a rapid by-pass channel if choking or other trouble developed in the hammer mill.

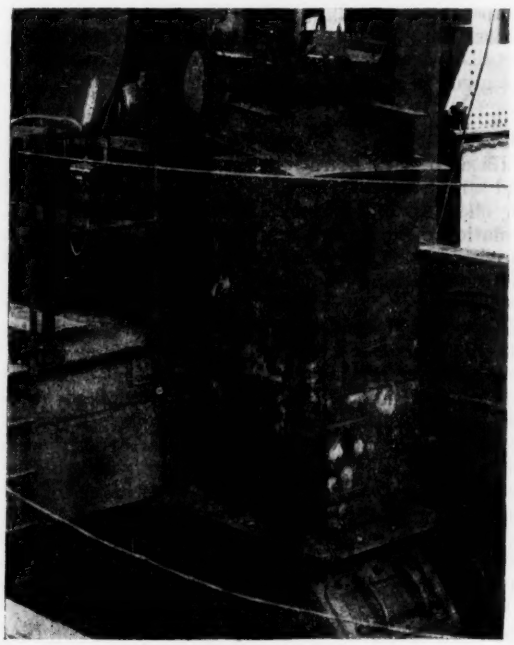


Fig. 13—Horizontal conveyor feeding to hammer mill (for location *see* Fig. 1)

With the arrangements finally adopted it was not possible to crush ore or coke alone, but only the mixture of all the materials. However, the feed of mixture rather than unmixed ore was undoubtedly a help in prevention of choking. Further, a high degree of intimate mixing of components was obtained, and this was found to assist the sintering process to a marked extent. On the other hand, it was impossible to separate the effects of control of size of ore and coke, and the inclusion of the coke led to rapid wear of the hammer tips.

Free fall of material both into and out of the hammer mill was not readily obtained, and this limitation caused some difficulty in maintaining an unobstructed flow into the mill. Further, the discharged material was thrown very firmly against the discharge conveyor, resulting in a somewhat agglomerated product and not a fluffy free-running material. Adverse effects on the sintering process were sometimes observed as a result of this.

The machine proved a serviceable experimental tool for providing a mixture free from material above $\frac{1}{4}$-in.–$\frac{3}{8}$-in. size, in which ore and fuel were intimately and, in general, suitably mixed. Experimental production of sinter from this hammer-milled mixture was consistently practicable, and it was possible to carry out trials with some approach to control of raw-materials properties and to observe effects of plant and process variables other than those of the preparation of the raw materials.

(*b*) FEED TABLES

It was not found practicable to carry out alterations to the feed tables, although the fluctuations in feed rate were shown to be most important in causing variations of quality. This was because modifications would have involved major alterations not only to the feed-table mouth, but also to the concrete walls of the bins. In the experimental work continuous adjustments of the table speeds and gate opening were made to maintain controlled feeds, and the actual rates were observed for subsequent analysis of fluctuation.

(*c*) PROVISION OF HEARTH LAYER OF RETURNED SINTER

The hearth layer is normally obtained by segregation of the larger pieces by the swinging-spout mechanism. No discrete layer is formed, however, so that if combustion is prolonged, fused materials adhere to the bars, which may burn and finally break. Moreover, the sealing of the edges and joints of the grate are never mechanically perfect, so that loss of fine material may occur, even to the extent of forming large holes in the sinter surface.

It was considered therefore that the trials should include investigations of the value of providing a hearth layer by a more positive controlled mechanism to obtain an adequate and uniform thickness. A number of alternative proposals were considered, in all of which provision was made for continuous operation of a new belt conveyor or bucket-elevator

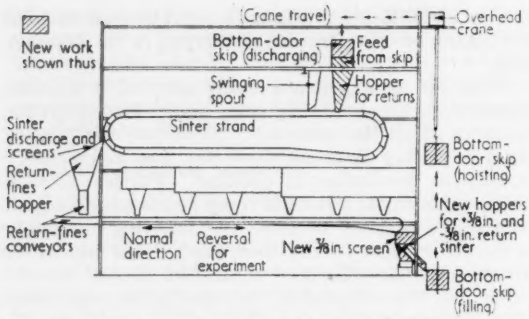


Fig. 14—System and scheme of operation for experimental deposition of hearth layer with return sinter (*see* also Fig. 1)

system to move sinter from the return-fines system to the swinging-spout positions of the strand, after screening to eliminate materials less than $\frac{3}{8}$ in. The lengths of conveyor or elevator required were, however, very great, and the possible range of positions very limited. After much preliminary design work it was finally decided to install a system for batch operation of limited duration. A hopper was suspended immediately above the strand and arranged to feed screened sinter immediately previous to the feed of the mixed raw materials, the rate of feed being controlled by allowing the moving strand to drag the sinter from the hopper through a narrow slit opening. By reversing the existing belt feeding return fines, sinter already screened by the static screen at the discharge end was fed on to a vibrating screen, and the material under $\frac{3}{8}$ in. removed. The oversize was fed to skips, hoisted by the existing plant travelling crane, and then discharged into the hopper above the strand. The capacity of the whole system of hoppers and skips was about 10 tons of sinter. The arrangements are shown diagrammatically in Fig. 14 and the locations of components on the plant are shown in Fig. 1.

This temporary arrangement had the disadvantage of a limited running period. The hopper and skips were of little greater capacity than that required to provide a hearth layer for two complete strand lengths. Therefore, apart from the intermittent operation, a true balance between return sinter in the hearth layer and that mixed with the raw materials could not be obtained ; the sinter in the hearth layer was also of a quality different from that produced in the trials, rendering assessment less precise than otherwise attainable. In spite of these apparent drawbacks it was, however, found possible to carry out a few trials of sufficient duration to assess the value of separate hearth layering.

(*d*) AIR-FLOW CONTROL VALVES

The plant was originally fitted with a butterfly control valve in each windbox leg, but trouble is experienced with such valves as a result of abrasion and corrosion of the moving parts. The possibility of replacing these valves by normal gate types was therefore examined, but unfortunately there is no design available which will meet the difficult operating conditions. Further, it was felt that the proportion of experimental to total running time would be small, and because of these two considerations no step was taken to design and install an improved valve. Simple plate ' slides ' were used for first experiments. These are cumbersome to handle, but proved sufficient for the limited number of trials that were carried out. The trend of results obtained in experiments on the air volume and distribution suggested that the influence of these factors was not of such over-riding importance as some other plant variables. Accordingly, no further measures were taken to extend or refine the individual windbox control methods.

INSTRUMENTATION

In the initial stages of planning the trials it was thought that measurements and records of the physical conditions of sintering would be essential, and that additional instruments would be required. The original instruments in the plant were (1) feed-table-speed indicators, (2) feed-table-motor current indicators, (3) strand-speed indicator, (4) dial indicator for suction at fan inlet, (5) water gauges for suction at windboxes, and (6) flow indicator for gas consumption by ignition furnace.

Additional instruments were thought to be necessary for recording temperatures attained in the sinter bed, and the temperature and velocity of gas in each windbox.

As the trials contemplated were comprehensive and probably difficult to repeat satisfactorily it was considered desirable to obtain a complete record of the measurements, in preference to observations of indicating instruments. The requirement for orthodox recorders would have been formidable, and it was therefore decided to use the technique of recording the readings of simple indicating instruments by ciné-camera, using direct millivoltmeter indicators for temperatures and dial-reading aneroid or fluid manometers for suction and air volume, respectively. Details, together with the methods of experiment, are given in Appendix IV.

SAMPLING METHODS

Input Sampling for Physical Assessments

Rates of flow of raw materials were determined, and samples of materials and mixtures were obtained for chemical and physical assessments. The determination of flow rates was carried out by running a tared tray along the constant-speed delivery belt and directly weighing the material collected (*see* Fig. 11). In many cases the direct weight readings could be dealt with as indicators of the constancy of feed rate, but the importance of fluctuations became so clearly recognized at later stages of the work that a method was developed to compute the percentage rates directly from the sampling-tray weights. A simple electric computing instrument was constructed with dials so calibrated that actual tray weights could be set by graduated controls and the percentages of raw materials read directly. This was found valuable in setting the plant feeds to deliver as near as possible standard percentages of raw-materials components. A description of the instrument is given in Appendix IV.

Input Sampling for Chemical Assessments

Samples for chemical analysis were obtained in the orthodox manner by collection of increments over an

appropriate time, followed by mixing, quartering, and dividing as required. The rapid determination of water in the mixed raw materials was attempted on a number of occasions by different methods, but none was found really satisfactory, and reliance was ultimately placed on direct determination subsequent to the trials.

Output Sampling

The most useful output-sampling method proved to be that of raising single pallets from the strand, immediately before discharge. It was possible to arrange this with very little loss of time. The method has the advantage that when observations are made of fluctuations of raw materials over a short period, and the particular pallet concerned is raised after sintering, the observations can be regarded as being peculiar to it.

A number of attempts were made to sample over a long period of production. The quartering of one complete wagon load was first attempted but proved a formidable task which was impracticable for regular assessment work. Ultimately a mechanical sample divider was set up on a mobile truck which could be driven independently of the rail traffic, with its receiving hopper immediately below the discharge chute, and so receive sinter as made in small increments. The total sample was then fed through the cone mixer and divider built below the hopper. The performance of this equipment was satisfactory when the sample was not too hard, but difficulty was encountered in dealing with large slabs of strong sinter. The trials to estimate the performance of this sample divider are reported in Appendix IV.

In practice, the pallet-sampling technique was found more useful than the incremental methods, which were regarded only as supplementary whenever used ; a completely satisfactory system has yet to be devised.

Appendix II

SPECIAL DEVELOPMENT OF THE HAMMER MILL FOR TREATMENT OF STICKY ORE

The experiments leading to the choice of the high-speed hammer mill for reduction of the size of the sticky ore fines have been described in Appendix I. The machine chosen and installed was designated the No. 3A Multi-Hammer Pulverizer by the manufacturers, Messrs. Edgar Allen and Co., Ltd., and although it held out more promise of successful operation than other types tried it was not possible to obtain an uninterrupted supply of finely crushed ore or mixed raw materials from it without development.

FIRST STAGES OF EXPERIMENTAL OPERATION

The first trial of the mill as supplied was carried out during November, 1947, using normal Corby raw materials. The mill ran with no trouble for 2 hr., but the crushing efficiency appeared to deteriorate towards the end of the run. There was considerable wear on the hammer tips, and it was evident that if wear continued at that rate long trials would be impossible. Fines built up on the back wall of the mill and formed an obstruction extending upwards into the feed chute, but not sufficient to cause operation to cease. As a first step, to take up the wear on the tips, the breaker-plate setting was closed up and a further trial carried out. The crushing efficiency was not improved, and the crusher choked within a few minutes. Material appeared to have started building up in the corners of the casing, gradually growing across and outwards until the opening to the mill was insufficient for the flow of material (*see* Fig. 15). The surface of the built-up fines next to the hammers was extremely solid, but behind this the material was only loosely packed. The breaker plate was reset to its original position and a further trial was attempted, but after a 20-min. run choking again took place.

An attempt was made to reduce the stickiness of the fines by the addition of about 20% of return sinter to the raw-material feed. A period of 20 minutes' running was obtained at a time when the normal mixture immediately choked the pulverizer, but examination of the hammers showed extremely rapid wear on the edges.

At this stage it was thought that the choking was partly due to the position of the feed chute. The raw mixture discharged from the bucket elevator had to slide down an inclined chute before falling into the crusher. It was considered that if the material was allowed to fall vertically for several feet, fines would be less likely to build up, and the flow of material would tend to remove any accretion which formed. A vertical chute with horizontal conveyor was therefore erected in place of the inclined chute from the bucket elevator, and the hammers were reversed to give a new striking face (*see* Fig. 13).

An hour's uninterrupted run was obtained with the normal feed. The hammers and chute were then examined. The hammer edges were rounded, with up to $\frac{1}{4}$-in. radius, and there was some obstruction in the chute. The trial was recommenced with a feed of only 45 tons/hr., which is about two-thirds the

Fig. 15—Build-up of materials in first trials of hammer mill

normal value, but after 1 minute's running the chute was choked. In three further tests on a two-thirds feed, running times of 12, 2½, and 20 min. were obtained before choking.

A trial was then carried out using only green-ore fines in the feed to the mill. These are free from very sticky clay, and it was thought worth while to investigate the possibility of using them exclusively, at about 70% throughput, to carry out a series of assessment trials without the trouble experienced with mixed ore. The first evidence of choking occurred after 25 min., but crushing continued for 40 min., when a plant stoppage interrupted the test. The crushing performance was very good and it was easy to break down the small amount of built-up fines. At this time a small quantity of hematite concentrates became available in the raw mixture, and opportunity was taken of assessing the performance of the hammer mill with this addition. About 10% of Sierra Leone concentrates were being used. The mixing of the concentrates was very successful and a run of 30 min. was obtained before choking occurred ; the obstruction was easily cleaned, as the small concentrate flakes appeared to act as a lubricant. It was, however, undeniable that all these trials were of trifling duration, and it was quite clear that performance both as regards wear and throughput must be greatly improved.

MECHANISM OF CHOKING

Before describing the next stage in development it is worth noting that views on the cause of choking were evolving as more experience was gained on the performance of the hammer mill. There was no doubt that choking was the result of successive building of fines on the back wall and the bottom of the feed chute. It was evident that the hammer tip was responsible for most of the crushing, and that as the corners of the hammer tips wore back shorter runs were obtained before choking occurred. Choking was regarded as being the result of the following two interconnected factors :

(1) As the raw material fell into the hammer mill it would hit the striking face and be projected away at an angle dependent upon the wear on the hammer tip. Whilst the tip remained sharp the material would be projected at right angles to the face of the hammer and would be thrown against the back wall and breaker plate of the mill. But as the tip edge began to wear, this angle of the projection would vary accordingly, and the material would tend to be projected in an upward direction into the bottom of the feed chute.

(2) If the new hammers were regarded as cutting tools, any accumulation of fines would be cut through and could not maintain itself. When the hammers became slightly worn, however, instead of a cutting action there would be an impacting action owing to the rounding of the tips, and a hard compact agglomerate of fines would form next to the hammers. Thus, further accumulation would be encouraged until the pulverizer ultimately choked. This agreed with conditions found in practice. It was noted on examination of the obstruction that the first inch or so of material next to the hammers was very hard, but after penetration of this the material behind was quite soft.

TREATMENT OF HAMMERS TO INCREASE RESISTANCE TO WEAR

The next stage of development was clearly the extension of the running time of the hammer mill by reducing the hammer wear. The original hammers were of alloy steel (carbon 0·6% ; chromium 0·6% ; manganese 0·6%) heat-treated to obtain a Brinell hardness number about 500. To increase this hardness a set of hammers was treated by various methods to obtain harder wearing faces, the hammers of each row on the rotor being as far as possible treated identically. Six rows of six or seven hammers were treated in all. To one row, sintered-carbide tips were brazed, to a second row high-speed (tungsten alloy) steel ends were welded, and to the remaining four rows various hard-facing alloys were deposited by the familiar welding method, using hard welding rods. In addition to the foregoing, ten of the normal hammers supplied by the makers were used.

The hammers were placed in the mill according to the code shown in Table XII. The condition of wear on each of these rows was noted after running periods of ¼, ½, 1, 2, and 3¾ hr., and results obtained are given in Table XIII. The feed to the sinter plant was as usual, no extra additions of any material being made, and no attempt was made in any way to interfere with the fines building up in the hammer mill during this trial. After the first 2¼ hr. the hammers were removed and a hammer from about the centre of each row was photographed (*see* Fig. 16). The hammers were replaced in opposite order, *i.e.*, the hammer on the right-hand side was now on the left-hand side, and in addition new edges were used for row Nos. 1, 3, 5, and 7. The trial was then continued for the further 1½ hr.

From the information obtained it was evident that the only class of tip showing anything like the wear resistance required was the cemented-carbide type. After 3¾ hr. the cemented carbide had scarcely worn

Table XII

FIRST DURATION TRIAL OF HARD-FACED HAMMERS IN HAMMER MILL

Row No.	Position of Hammers	Code of Hammer Types	
1	N N N N N N N	N, normal	
2	C C C C C C	C, with carbide tip	
3	X N XA XH XA XHX	X, XA, XH	Various welded hard faces
4	P Y Y Y Y Y	Y	
5	N Z Z Z Z Z Z	Z	
6	P P P P P P	P	
7	Q Q Q Q Q Q P	Q	
8	N T T T N N	T, with tool-steel tip	

Table XIII

CONDITIONS OF ROWS OF HAMMERS IN HAMMER MILL AFTER VARIOUS PERIODS OF USE

Row No.	Wear After 15 Min	Wear After 30 Min.	Wear After 1 Hr.	Wear After 2 Hr.	Wear After 3¾ Hr.
1	Definite rounding of tip edge. Corner of tip worn	More rounding of tip edge, about $\frac{1}{8}$ in. round	Corners round. Edges rounded $\frac{1}{8}$–$\frac{1}{4}$ in.	Varying wear. Up to $\frac{1}{2}$ in. wear on top surface	...
2	Very slight wearing of tip edge. Trace of undercutting on braze metal	Similar to first 15 min.	Slight wear at corner of tip. Edges still showing very little wear. Definite undercutting	Some scarcely worn at the tip edge. Right-hand-side hammers rounded $\frac{1}{32}$ in. Pronounced undercutting of the steel, no preferential attack along braze	Slight wear ($\frac{1}{16}$ in.) on the tip edge. Undercutting progressing slowly
3	Hammer-type X. Corner of tip worn	Similar to first 15 min.	Less wear than other types in this row	Tip edges worn $\frac{1}{8}$–$\frac{1}{4}$ in. round	...
	Hammer-type XA. One similar to normal-type hammer. The other badly worn at the corners	Tip edge about $\frac{1}{8}$ in. round	Tip corners wearing	Wear on edge from $\frac{1}{4}$–$\frac{1}{2}$ in.	...
	Hammer-type XH. Slightly worse wear than other types, probably bad finish	Worn about $\frac{1}{8}$ in. round on tip edge	Tip corners showing most wear	Wear on edge from $\frac{1}{4}$–$\frac{1}{2}$ in.	...
4	Slight wear on tip edge	Corners starting to round	Tip edges and corners rounding; $\frac{1}{16}$ in. wear on edges	Wear on edge $\frac{1}{16}$–$\frac{1}{8}$ in. Greatest wear on right-hand side	Wear progressing slowly, about $\frac{1}{8}$ in. round
5	Rather badly worn. Worse than normal set	Wear on edge about $\frac{1}{4}$ in.	Tip corners badly worn	Wear on edge about $\frac{1}{2}$ in.	...
6	Similar to row 4	Slight wear at corners. One hammer slightly chipped	Similar to row 4	Similar to row 4	Tip edges worn $\frac{1}{16}$–$\frac{1}{8}$ in., corners slightly more
7	Tip edges rounding, but not so severe as row 3	Tip corners showing wear	Corners badly worn, edges $\frac{1}{8}$–$\frac{1}{4}$ in.	Wear on edge about $\frac{1}{4}$ in. Better than row 1	...
8	Slight wear on tip edge	Slight rounding of tip edges. Corners starting to wear	Edges worn slightly less than $\frac{1}{16}$ in.	Wear on edge about $\frac{1}{16}$ in.	Edges worn about $\frac{1}{8}$ in. Corners slightly more
Condition of Feed Chute	Build-up extending over halfway across chute, fairly soft	Build-up halfway across, soft	Build-up halfway across, soft	Build-up about $\frac{3}{4}$-way across, tending to be hard	Similar to previous

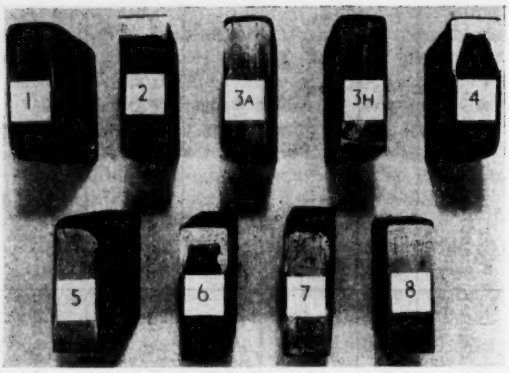


Fig. 16—Condition of representative hammers from each row after first duration trial. The hammers are numbered according to the notation used in Table XII

more than $\frac{1}{32}$ in. round on the cutting edge, whereas the next best types, including tool steel, had all rounded by $\frac{1}{2}$ in. A problem with the carbide tip was the undercutting experienced, this being most serious just below the tip but extending about $1\frac{1}{2}$ in. towards the shaft. After consultation with the makers a new design of carbide tip consisting of a wedge of carbide $2\frac{1}{2} \times 1\frac{1}{4} \times \frac{1}{4}$–$\frac{1}{8}$ in. brazed to the hammer was evolved.

Subsequent to the above test a further trial was carried out without any cleaning of the chutes. The mill choked within 6 min., and it was believed that the accumulated fines had stood so long without removal, and thus become so hard, that the hammers could not shift them. This proved to be correct, and two further trials of 56 and 20 min. were obtained with little difficulty after the built-up fines had been cleared. In the next trial choking occurred after only a few minutes and, despite complete cleaning, the pulverizer choked on restarting. It was then considered that the useful life of most of the hammers had been reached and that only those with carbide tips were doing any useful work.

While awaiting delivery of the new type of carbide hammers it was decided to examine the effect of running the hammer mill with only half the usual hammers. A short trial of 10 min. duration was carried out, running with the four rows of hammers equally spaced. The best hammers from the previous trials were used and the machine worked quite satisfactorily, though there was the usual partial obstruction over half the chute. The size of the product was greater than that obtained with the full set of hammers, and the mixing was not so thorough.

TRIALS WITH NEW DESIGN OF CARBIDE TIP

Trials were resumed when three rows of the new cemented-carbide-tip design, one row of the original carbide-tip design, and four rows made up from the best of the other types, were available. The carbide-tipped hammers were equally spaced in the hammer mill. Trials with this arrangement were not successful; only a few short runs were obtained before choking occurred, and it was decided to remove all but the hammers with cemented-carbide tips.

A run of 1 hr. 11 min. was then carried out successfully. Examination of the hammers showed that five tips of the new type were missing; the failure appeared to be due to faulty brazing. Further trials with this set were carried out without more loss of tips, and altogether a total of 5 hr. 40 min. running time was obtained. The hammer tips showed very little wear, though the undercutting on the original carbide tip was still progressing.

The plant operators stressed the desirability of obtaining a long continuous run, and although this could not be arranged, two shifts of uninterrupted work were attempted following the previous total of 5 hr. 40 min. The feed to the hammer mill was limited to 60 tons per hour. Accumulations of fines in the chutes or the hammer mill were cleared only during plant stoppages arising from causes not connected with the trial. The hammer mill worked satisfactorily throughout the test, although slight choking occurred on one or two occasions owing to increase in the feed rate. The machine was not stopped for these interruptions, but the plough mechanism was raised until it cleared itself. A total running time of $10\frac{1}{2}$ hr. was obtained from the $15\frac{1}{2}$ hr. of shift work, the 5 hours' total delay being made up as follows:

Plant stoppages not connected with the trial	4 hr. 24 min.
Stoppages for sampling	20 min.
Stoppages due to cleaning small conveyor	9 min.
Stoppages due to choking of hammer mill	7 min.

The hammers were removed after this trial for examination, and were photographed (*see* Fig. 17). Rows *A*, *B*, and *C* had then had 16 hr. 10 min. total running time and row *D* had had $21\frac{1}{2}$ hr. The varying wear on the hammer tips can clearly be seen in Fig. 17;

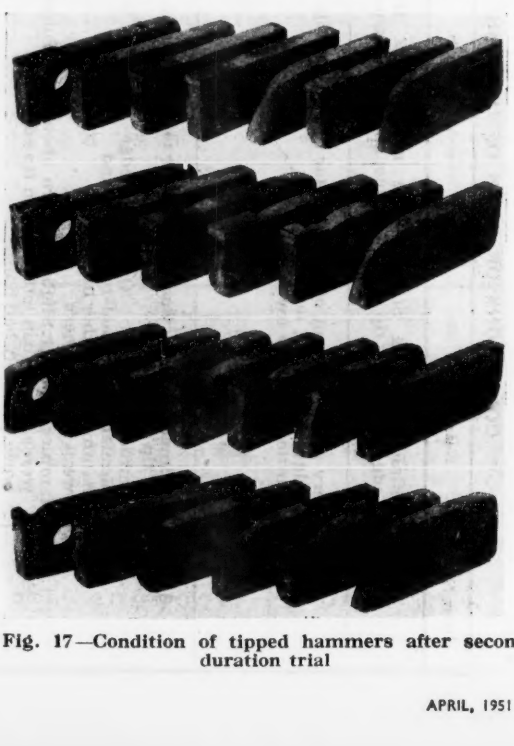
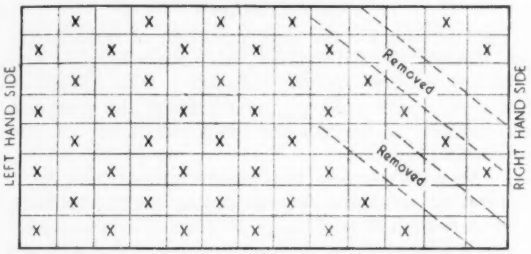


Fig. 17—Condition of tipped hammers after second duration trial

Table XIV
ARRANGEMENT OF HAMMERS IN FINAL TRIALS



some tips had chipped and others had broken off. During the trial period a few fragments of tramp iron had passed through the mill, and may have been responsible for some of the breakages. Some of the hammers showed very little undercutting but, even with the 2½-in. extension of carbide down the working face, others showed appreciable undercutting across the row. The wear was most severe on the left-hand side and gradually diminished towards the right-hand side.

FINAL TRIALS

Delivery of 30 hammers with the wedge-shaped tip was obtained shortly after the foregoing trial, and these, together with the best hammers from that trial, made a total of 44 carbide-tipped hammers which could be used. The hammers were placed in the mill in the order shown in Table XIV. It will be seen that eight hammers were short on the right-hand side, but as this side showed least wear it was decided to run the hammer mill in this manner until a full set of tipped hammers could be obtained. In practice this was not reached, as new hammers had to be used to replace those with broken tips. Tip failure was mostly due to poor brazing, and although various types of brazing material were tried the difficulty was not overcome. Most of the failures showed immediately on the first impact with the feed, but if they withstood this they were quite satisfactory. A new design, shown in Fig. 18, was developed over this period, and had the advantage that as the tip wore back the hammer could be removed after a period of service and reground to give a new sharp edge. Insufficient trials have been carried out so far to prove the value of this design.

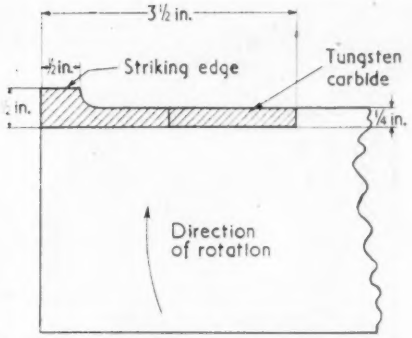


Fig. 18—Proposal for improved design of tungsten-carbide tip for hammer. (Not to scale)

At this stage of development the continuity of performance of the hammer mill was no longer a limiting factor in the execution of trials. The maintenance of the hammer profile was shown to be the factor governing the choking of the machine. When this profile was maintained, no instance ensued in which the machine was not able to deal with a throughput adequate for experiments, and other factors were found to impose more serious limitations of opportunity and duration of trials. Accordingly, no further development has been carried out, but this must not be taken to imply that the hammer mill is fully satisfactory. It is clear that much more work would be necessary to make the performance approach the requirements of operation in full-scale production.

Appendix III

METHODS OF ASSESSMENT OF SINTER PROPERTIES, AND RESULTS OF REDUCIBILITY MEASUREMENTS

It was recognized that while certain laboratory facilities could with advantage be supplied by outside sources, there were two classes of measurement which were regarded as essentially the duty of the British Iron and Steel Research Association team. These were the assessment of the physical and chemical properties fundamental in the recognition of sinter quality. Physically, quality is indicated by the size analysis and by changes caused by mechanical treatment, and chemically by the reducibility of the sinter compared with that of the ores smelted. Physical assessments were carried out on every sinter made experimentally, but reducibilities were determined only for certain samples representing selected or extreme values of physical properties.

In order to avoid uncertainties which might arise from transport of sinter samples before tests of physical quality, a small mobile test laboratory was established and kept at the site. It was equipped with a mechanical sieving machine capable of dealing with samples weighing about 1 cwt. and graded from 2 in. down to $-\frac{1}{16}$ in., a small sample divider, and a weighing machine; space was also provided for shatter-testing equipment. The layout is shown in Fig. 19.

ASSESSMENT OF PHYSICAL QUALITY

At the time of commencement of the work no standard methods of assessment were generally accepted, although procedures had been proposed by Pepper[4] and by the Appleby-Frodingham Steel Co.[6] for their own trials. The Appleby-Frodingham technique was adopted and was ultimately extended to give a 'dust-index' figure as well as a 'strength index.' The sample used for test was crushed entirely

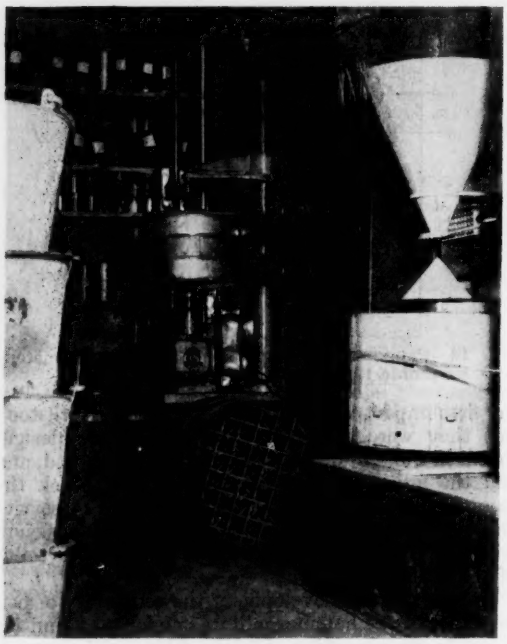


Fig. 19—Layout of mobile test laboratory

below ½ in. in size and a number of smaller (300 g.) samples were then subjected to two standard impacts in a drop-weight apparatus, shown diagrammatically in Fig. 20. The increase in percentage of — ⅛-in. material is then taken as the dust index and the percentage of — ½ in. to + ¼ in. remaining is taken as the strength index. The emphasis on the dust aspect rather than the strength arose in the course of the trials, when experience brought about a better appreciation of the qualities desirable in sinter.

The percentage of dust (— ⅛-in. material) in the sinter as made is also obviously a most important property of the product, and was determined for every experimental sinter on a comparative basis, as sampled from the pallet. It is clear that there can be no absolute basis for expression of the figures, as any practical point of sampling is really arbitrary,

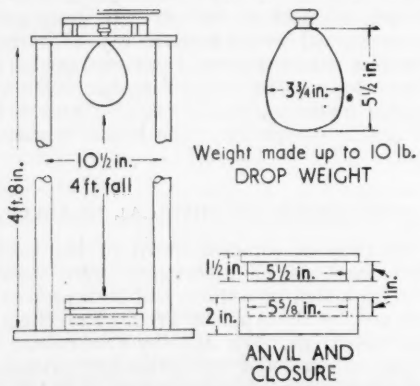


Fig. 20—Arrangement and principal dimensions of drop-test equipment

but the figure is widely used for comparison and its determination is important.

REDUCIBILITY

The method for the determination of reducibility was chosen after discussion with metallurgists and research workers of the industry. The choice of hydrogen as the reducing medium and the temperature of 750° C. for the reduction was made on the following grounds :

(1) Hydrogen is particularly suitable for comparative measurements as it cannot give trouble with carbon deposition.

(2) The reaction is rapid enough with hydrogen at 750° C. to approach completion after 2–3 hr., and to give figures for comparison in about 1½ hr., and thus does not occupy a time disproportionate to other assessments.

Both these factors are important in selecting a method for use as part of a number of assessments for field work, maintaining sufficient accuracy but not occupying an excessive time.

The apparatus used was quite conventional. Cylinder hydrogen was led *via* (*a*) the reducing valve through platinized asbestos maintained in a tube furnace at 750° C., and (*b*) magnesium perchlorate for drying, to a 5-g. sample of the sinter (— ¼ in. to + ⅛ in.) held firmly in a silica tube at 750° C. in the furnace. The water produced was absorbed in Midvale bulbs filled with magnesium perchlorate, arranged so that they could be readily changed. The hydrogen flow was regulated by a liquid differential manometer to about 2 g. per hour. The sinter was degassed by heating *in vacuo* to 750° C., the whole apparatus evacuated, and hydrogen admitted stage by stage. As soon as reaction commenced the water produced

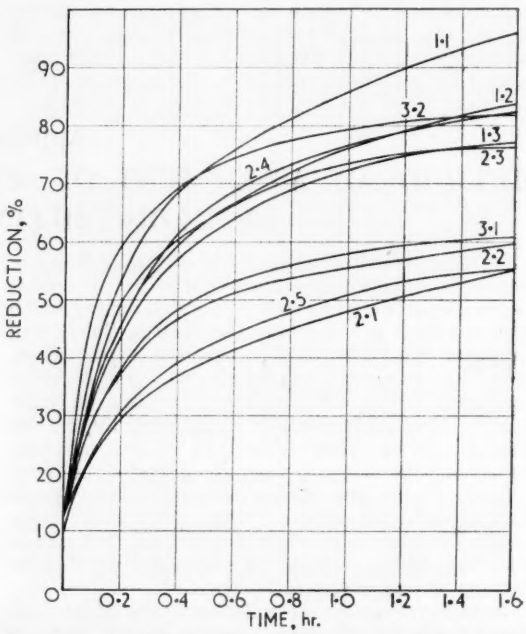


Fig. 21—Rates of reduction of experimental sinters by hydrogen at 750° C. (Serials 1, 2, and 3)

was weighed, first at 6-min. and then at 12-min. intervals.

From the successive weights obtained the rate of oxygen removal was calculated, the initial stage of oxidation of iron in the sinter being determined from the analysis. From these two factors the rate of reduction was plotted.

Extent of Reducibility Measurements, and Results Obtained

In the first three series of trials, sinters were produced from raw materials of selected size, some of the ores and cokes used differing from the normal Corby materials. The sinters obtained had a wide range of physical properties. Reducibility measurements were made on each of these sinters. In order to determine the significance of variation, the range of values of reducibility for a number of samples of the same sinters was also investigated, together with the values for different fractions of the same sinter in which the sintering process had taken place to varying stages of completion.

Figure 21 shows the results for a number of the experimental sinters, Fig. 22 the variability of samples from one selected sinter, and Fig. 23 the different values attained by fragments varying from just-calcined to fully sintered material. From these it is clear that the variations occurring between samples from the same sinter are of the same order as those occurring between sinters made under different conditions.

A series of comparative reducibility determinations was also made in connection with the attempted correlation of sinter properties and furnace behaviour. The results of this work are shown in Fig. 24, and a much wider range of reducibilities is indicated. It is possible, with high iron contents, to obtain simultaneous excellence in physical properties and a high relative reducibility, but nevertheless the low reducibilities (especially at the 60% deoxidation stage) of the lean-ore sinters with best physical properties were associated with good furnace driving, fuel economy, and high output.

It therefore seems that the specification of reducibility is more difficult than the specification of the physical properties, and in this light it is felt that

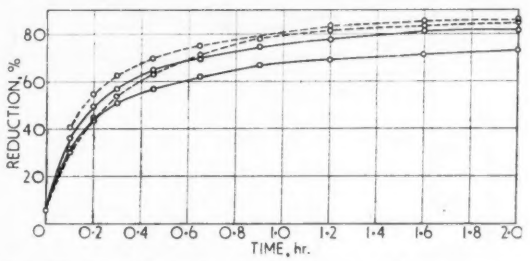


Fig. 22—Variation of reducibility of random samples of experimental standard sinter. (Reference 1/3)

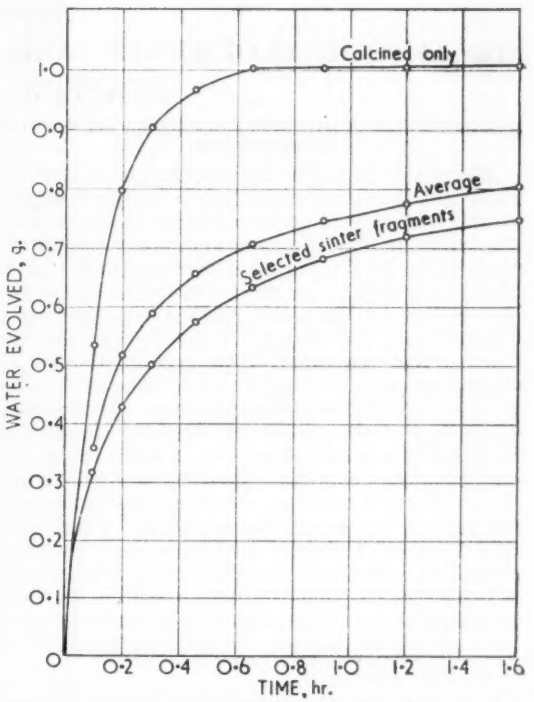


Fig. 23—Approximate comparison of reduction rates of fractions selected from heterogeneous sinter. (Experimental (standard) sinter, reference 1/3)

the extent of reducibility determinations in the present work is not inadequate. Recent work has shown quantitatively the increase of furnace coke consumption caused by ore of low reducibility, and further work on sintering must always include reducibility determinations to keep the order of magnitude measured. Assuming that other properties are consistently good, a sinter of good reducibility will certainly show advantages, and the problem of improvement of this property is therefore important.

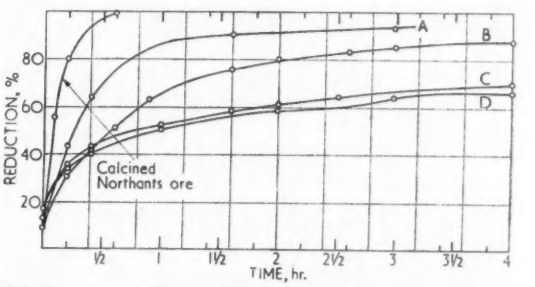


Fig. 24—Comparison of reduction rates of sinters, at 750° C., in hydrogen

Appendix IV

SPECIAL DEVELOPMENTS AND TRIALS OF INSTRUMENTS AND SAMPLING EQUIPMENT

INSTRUMENTATION FOR RECORD OF REACTION CONDITIONS

A note has already been given (Appendix I) of the additional instruments which were installed experimentally, in order to permit more precise observation and recording of such fundamental quantities as the temperature attained in the sinter during the process of combustion, the temperature of the waste gas and its variation over the period of the process, the suction attained, and the velocity of gas through the raw material and the sinter. The desirability of such experiments seemed apparent at the time of planning the programme, but the performance of the normal assessment trials proved to demand considerable resources of technica' manpower, so that experiments combining control of sintering conditions and precise observation and recording of leading physical quantities have so far proved beyond reach. A few trials were, however, carried out to make assessments during normal practice to determine the orders of magnitude of quantities involved and their variation, and it is considered that some account of these should be given for completeness and possible subsequent value.

Method of Observation

In order to obtain records of the quantities measured it was decided to set up all the instruments as indicators, as closely grouped as possible and to record the dial readings photographically. This is an extremely flexible technique, permitting either continuous or intermittent records as demanded by the rate of variation of the quantities under observation. The grouping of dial and manometer indicators is shown in Fig. 25. A 35-mm. Bell-Howell ciné-camera was used to obtain the records, taking a small number of photographs at one time and continuing at intervals for the duration of the trial, this normally being the time of travel of one pallet along the strand. Illumination was provided by four photo-flood lamps set in simple reflectors about 5 ft. from the dials. The types of indicator used were as follows :

The suction of individual windboxes was measured by 4-in. dial aneroid meters, having 360° deflection for the 20 in. W.G. normally attained. These were connected by ⅜-in. copper pipes to the windboxes, just at the entry to the suction manifold pipes.

The velocity and volume of air passing through each windbox could not be measured with great accuracy, as the layout of the airstream was very unfavourable. It was, however, decided to attempt comparative measurements with double-headed (up and down stream) pitot tubes, with twin-fluid constricted **U** tubes as indicators. Single limbs of these **U** tubes, with the twin-fluid interface, are shown on the instrument board (Fig. 25). Such **U** tubes permit the observation of a change of interface level much

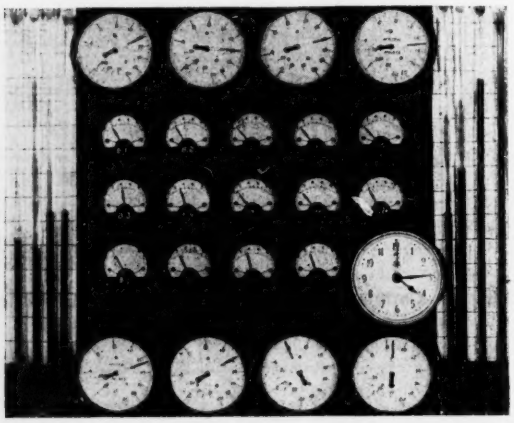


Fig. 25—Dials and manometers grouped for photographic recording

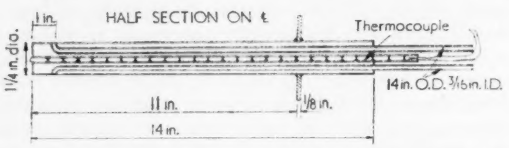


Fig. 26—Pitot head with replacable thermocouple for measurements in windboxes

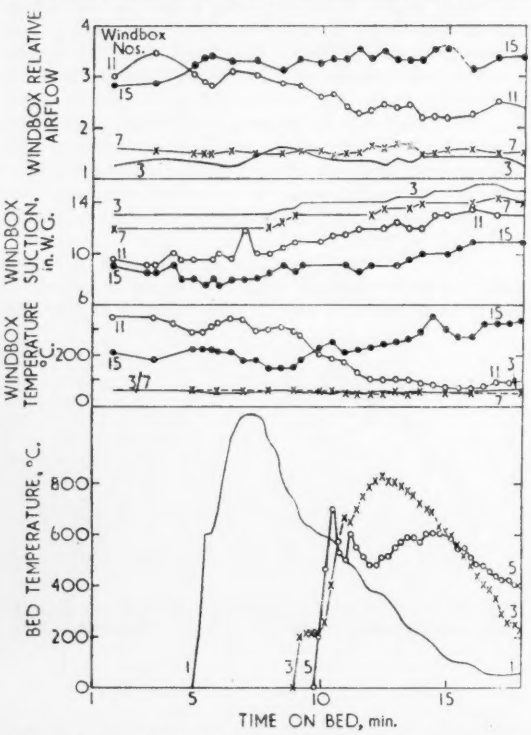


Fig. 27—Typical observations with instruments carried out 29/10/47

greater than the actual pressure head ; using paraffin and alcohol as the two fluids and a $\frac{3}{16}$-in. U tube joining $\frac{1}{2}$-in. upper limbs, a pressure difference of 1 in. is observed as an interface movement of 4 in.

Individual windbox temperatures were measured by temporary thermocouples made from copper and Constantan wires of about 22 S.W.G., insulated by glass silk coverings and inserted only for the duration of experiments into the double pitot heads (*see* Fig. 26).

The temperature attained in the reaction zone was measured by three sets of twin platinum–platinum/13% rhodium thermocouples, the thermal e.m.f. being indicated by directly connected 2-in. dial millivoltmeter instruments. The thermocouples were calibrated directly in a resistance furnace to about 1300° C., and higher readings were obtained approximately by extrapolation.

The thermocouples were all fitted into one specially prepared pallet by bayonet fastenings, and were inserted immediately before feeding the raw material, trailing leads being used to maintain connection to the indicating instruments during the travel of the machine.

In general, all these methods were found practicable, and observations were made by these means during representative production periods. Recorded figures were read by a strip projector or a low-power microscope. A typical plot of results is shown in Fig. 27. In this particular example an insufficiency of carbon in the raw materials was suspected, and the low value of the maximum temperature recorded (1000° C.) in the reaction zone may be related to this. Other points worthy of note are the late rise of temperature at the lower, but not the lowest, level of the sinter bed, and the rapid rise of air velocity only at the end of the strand travel.

RAPID COMPUTER FOR PROPORTIONS OF RAW MATERIALS

As the standard of observation and control in the trials improved, the problem of maintaining constancy of the proportions of raw materials became more critical. In detail, the operation comprises a written record of the weighing, correction for tare of sampling tray, and calculation of percentages. This cannot be readily reduced to a simple routine, as not only may fluctuations occur in the relative rates of feed of the separate raw materials, but the total rate may also vary, and some means of rapid indication of raw-materials percentages became urgently required. Rapidity is extremely important, as any delay in computation leads to a lag between observation and correction, and stable control cannot be obtained.

The first approach to a method for the measurement indicated was a proposal for a nomogram or a slide rule, or one of the possible combinations of the two in which the cursor indication is taken from a line indicating the variation of the observed quantity. It was, however, thought that an electrical circuit could be devised to indicate directly the percentages represented by observed weights adding up to a variable total. It was considered at the outset that it would be theoretically sounder, and also simpler, to execute the calibrations and measurements if a device were used to measure voltage rather than current, in ratios corresponding to the ratio of raw-material feed rates. While the voltage scheme can be regarded as an approachable ideal, it was found that current measurement had some favourable points in practical operation and this type of circuit was finally used (*see* Fig. 28). The complete instrument consists simply of three circuits in parallel, each comprising a milliammeter and variable resistance. The variable resistances are calibrated so that currents of a magnitude proportional to the several rates of flow of raw materials can be maintained through the individual meters. The total current from the three parallel circuits passes through a control meter, and the voltage applied to the whole network is then varied to bring this meter to a standard total reading.

The procedure of operation is rapid and simple. The 'ore knob' is adjusted to correspond with the weight of tray plus ore, the 'coke knob' to tray plus coke, and the 'flue-dust knob' to tray plus flue dust. The variable resistance is adjusted so that the fourth (total current) meter reads 100. The three meters then show the percentage of ore, coke, and flue dust, and the fifth meter shows the total through-

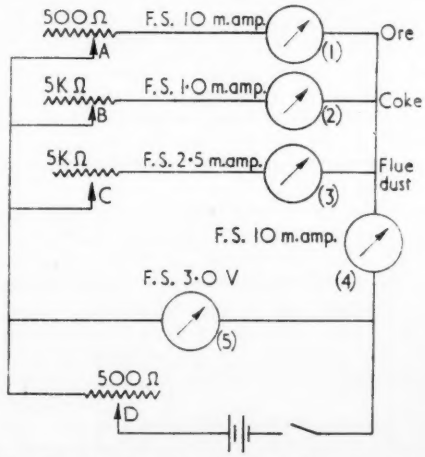


Fig. 28—Circuit of rapid computor for proportions of raw materials. Operation: (*a*) Adjust A, B, and C to correspond to the weights of tray plus sample; (*b*) adjust D to give full-scale deflection of meter 4. Meters 1, 2, and 3 give percentages of ore, coke, and flue dust, respectively. Meter 5 is calibrated to show tonnage of raw materials per hour

Fig. 29—Mobile sample divider

Table XV

TESTS OF EFFICIENCY OF SAMPLE DIVIDER

Test No.	Method of Sampling	Size Grading, %						
		−3 to +2 in.	−2 to +1 in.	−1 to +½ in.	−½ to +¼ in.	−¼ to +⅛ in.	−⅛ in.	Weight, oz.
1	Divider (1)	...	6·6	21·9	36·2	13·3	21·9	1701
	Segment (2)	0·7	4·0	24·9	35·8	13·3	21·4	1614
	Segment (3)	1·1	7·3	23·2	34·2	13·3	20·9	(1493)
	Segment (4)	0·8	6·7	23·4	36·4	13·2	19·4	1715
	Hand-sampled fraction	1·3	6·9	21·7	36·0	13·3	20·8	...
2	Divider (1)	...	10·2	35·7	33·4	10·4	10·3	1121
	Segment (2)	...	8·6	37·7	32·0	10·5	11·2	(732)
	Segment (3)	...	8·5	34·8	35·1	10·6	10·8	1114
	Segment (4)	...	10·3	36·8	32·4	10·0	10·4	1173
	Hand-sampled fraction	...	5·4	29·3	39·0	11·5	14·9	...

put in tons per hour. The accuracy of reading was checked by calculation after each trial. With the commercial components used the error was about 2% of each reading.

MOBILE SAMPLE DIVIDER

The method of pallet sampling may involve a plant stoppage of about 10 min. for changing pallets and moreover does not give a representative sample of the sinter discharged from the plant, as the sinter should pass over the return-fines screens. The hand sampling of the pallet involves coning and quartering the material, takes time, and introduces a random personal error. In an attempt to eliminate these shortcomings a mobile sample divider was constructed, designed so that sampling might be carried out for a longer period than represented by a single pallet. The sampler was essentially a scaled-up model of the coke sampler specified in British Standard 1017 : 1942, a slightly larger throat clearance being provided for the larger size of material handled. A 3-in. grid was used on top of the collecting hopper to prevent choking by larger lumps of sinter. The sampler equipment was mounted on the rear of a four-wheel-drive lorry (Fig. 29). The lower receiving hopper was rotated by belt drive from an electric motor and reduction gear.

Trouble was at first experienced owing to large lumps of sinter choking the throat of the hopper, and this was overcome by placing a grid on top of the collecting hopper. A small hole through which a rod could be introduced to clear any blockages was also made in the throat.

Two trials were carried out to examine the efficiency of the divider. A sample was taken in the top hopper and divided down as explained. The four samples from the divider were assessed individually, and the discarded fraction from the divider was hand sampled by coning and quartering. The results obtained are

Table XVI

COMPARISON OF SINTER ASSESSMENTS BY HAND SAMPLING FROM PALLET AND FROM DISCHARGE CHUTE

Test No.	Method of Sampling	Size Grading, %								Dust Index	Strength Index
		−3 to +2 in.	−2 to +1 in.	−1 to +½ in.	−½ to +¼ in.	−¼ to −⅛ in.	−⅛ to +1/16 in.	−1/16 to +1/36 in.	−1/36 in.		
1	Divider (quenched)	0·7	7·2	23·4	40·0	15·0	9·0	3·3	1·3	...	...
	Pallet	2·0	21·0	29·0	28·0	8·8	5·0	1·6	4·5	...	...
2	Divider (quenched)	...	6·3	28·3	43·3	12·4	6·5	1·9	1·3	...	...
	Pallet	3·2	10·5	27·5	37·0	10·6	6·3	1·7	3·1	...	...
3	Divider (dry)	2·6	6·3	25·5	41·3	11·6	6·8	2·0	4·1	...	...
	Pallet	2·6	9·8	29·5	37·0	9·7	6·1	1·8	3·0	...	...
4	Divider (partly quenched)	13·8	9·0	20·9	33·3	11·3	6·4	1·7	3·4	17·8	68·5
	Pallet	12·6	11·7	27·7	32·8	8·1	4·1	1·1	2·0	14·6	71·3
5	Divider (partly quenched)	1·3	3·4	22·0	42·8	11·2	7·9	2·3	9·1	16·1	68·0
	Pallet	18·2	14·1	22·3	27·6	6·8	5·5	1·4	4·1	15·6	70·8

reproduced in Table XV. It will be noted that the four fractions from the divider are in close agreement over the smaller-size range, but above the 1-in. size larger discrepancies occur. There is some variation from the hand-quartered sample, probably owing to further breakdown on handling.

Trials were also carried out to compare the assessment of a sinter hand sampled from a pallet and a sample of the same sinter obtained from the discharge chute by the divider. It should be borne in mind that the sinter to the divider may be appreciably broken down by the fall into the discharge chute, even allowing for the beneficial effect of the static screens, and may have been further deteriorated by water quenching. The figures obtained are given in Table XVI. The results are very variable, but in general the sample from the divider is broken down to a smaller size, as expected. The high dust figures for the mechanical sampler may be due to breakdown of the larger lumps of sinter.

Acid Recovery from Continuous Strip-Pickling Lines

By J. Pearson, Ph.D., M.Sc., F.R.I.C., and W. Bullough, B.Sc., A.R.I.C.

SYNOPSIS

In a continuous strip-pickling line, acid concentrations are chosen to enable a predetermined hourly tonnage of steel to be completely freed from scale. If it is desired to incorporate an acid recovery system, so that ferrous sulphate is continuously removed from the spent pickle liquor and the free acid contained therein utilized, it is essential that the combined pickling recovery system shall be always in balance. The concentrations of acid and ferrous sulphate, and the volumes of liquor to be handled at any part of the cycle must be known in order that the correct choice of equipment may be made.

This problem has been treated in a general way, so that if the acid strength requirements are specified, the other relevant information can be calculated. A numerical example is given to illustrate the use of the method.

The results of determinations of the solubility of ferrous sulphate in sulphuric acid–water mixtures are given in an Appendix and an equation has been derived to enable the specific gravity of such mixtures to be calculated.

DUMPING of spent sulphuric acid pickle liquor is a practice to be avoided, and neutralization, particularly when large volumes have to be dealt with, is not considered a completely satisfactory solution. Methods which involve the removal of ferrous sulphate and the return of the mother liquor, with its associated free acid, to the pickling tanks are therefore being investigated. These methods have been described by Swindin[1] and Wragge,[2] but little appears to have been written about acid recovery as applied to continuous strip-pickling lines. In addition to reducing the consumption of acid, the return of mother liquors may represent a big saving of water, a commodity which is often none too plentiful. The separated ferrous sulphate, of course, requires disposal but this should be easier than disposing of spent liquors; it may eventually serve as a raw material for the production of sulphuric acid,[3] thereby making the whole process essentially self-contained.

The present paper is intended to serve as a guide to the application to pickling lines, of a cyclic system for continuous ferrous sulphate crystallization and acid recovery. In such a system, ferrous sulphate may be crystallized as copperas ($FeSO_4.7H_2O$) by cooling, or as monohydrate ($FeSO_4.H_2O$) by removal of water at temperatures above approx. 60° C. Even on cooling, monohydrate is deposited if the acid concentration is too high, so that the form produced, and therefore the type of crystallization equipment necessary, cannot be decided without a knowledge of the acid and ferrous sulphate concentrations at all stages in the cycle.

PICKLING-LINE CONDITIONS

The acid concentrations at the inlet and outlet ends of a line are chosen so that the required hourly tonnage of steel strip can be properly pickled. These concentrations depend on the nature of the scale and any processing (scale-breaking) it may have received, and should be determined by experiment or by reference to lines pickling similar material. In the outlet liquor, to avoid deposition in the pickling tanks, the concentration of ferrous sulphate must be such that its solubility is not exceeded. Even a value approaching the solubility limit may be

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too high, since the presence of dissolved ferrous sulphate reduces pickling rates, except at very high acid strengths.[4] The solubility of $FeSO_4$ in H_2SO_4–water mixtures is given in the Appendix.

If complete scale removal is to be effected in modern high-speed lines, it is necessary to add sulphuric acid, of a relatively high strength, continuously to the strip outlet end of the line. Some of this acid is dragged out by the treated strip and the rest cascades down the line dissolving scale from the steel. Acid concentration therefore decreases and ferrous sulphate concentration increases until the liquor is discarded from the strip-entry end of the line. Live steam is frequently employed for heating pickling tanks ; some of this may condense and dilute the liquor. If the spent liquor is treated for acid recovery, the mother liquors returned to the tanks will contain ferrous sulphate, since it is not feasible to remove this material completely from sulphuric acid.

Notation

In the following treatment, the symbol H_2SO_4 refers to pure sulphuric acid, while B.O.V. refers to the commercial acid (78% wt./wt.). All concentrations are expressed in wt./wt. percentages, *i.e.*, weight of material in lb./100 lb. of liquor ; the concentration of H_2SO_4, for example, is denoted by $[H_2SO_4]$. All weights are reckoned in lb./hr., with the exception of steel strip which is in tons/hr. The weight of H_2SO_4 reacting during the complete pickling of one ton of strip is, of course, not dependent on time and it is assumed that the thickness of the strip and the nature of the scale remain constant. The losses of acid, ferrous sulphate, and water from a pickling line through the removal of 'spray' by exhaust fans are indefinite, and no account is taken of losses occurring in this way.

The following notation is used :

A = $[H_2SO_4]$ in inlet liquor,
F = $[FeSO_4]$ in inlet liquor,
L = weight of inlet liquor,
a = $[H_2SO_4]$ in outlet liquor,
f = $[FeSO_4]$ in outlet liquor,
l = weight of outlet liquor,
D = drag-out coefficient, (weight of liquor lost in drag-out)/100T,
W_d = water gained or lost by steam heating, evaporation, and reaction of H_2SO_4 with scale,
B = H_2SO_4 reacting with scale on one ton of strip,
T = weight of strip.

A flow diagram showing a pickling line with acid recovery is given in Fig. 1.

Assuming that the liquor dragged out has the same composition as that entering the line, the H_2SO_4 lost in this way is DAT. Similarly, the $FeSO_4$ and H_2O lost are DFT and $D(100 - A - F)T$, respectively.

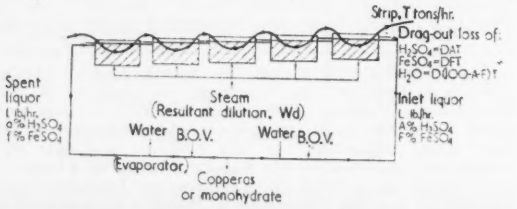

Fig. 1—Flow-sheet of a pickling line with acid recovery

Since the inlet liquor (L) contains $A\%$ H_2SO_4, $F\%$ $FeSO_4$, and $(100 - A - F)\%$ H_2O, and the H_2SO_4 reacting with the scale is BT, then

$$H_2SO_4 \text{ in outlet liquor} = LA/100 - BT - DAT \quad ...(1)$$

$$FeSO_4 \text{ in outlet liquor} = LF/100 + 1{\cdot}551BT - DFT \quad ...(2)$$

$$H_2O \text{ in outlet liquor} = L(100 - A - F)/100 + W_d - (100 - A - F)DT \quad ...(3)$$

where 1·551 is the conversion factor for H_2SO_4 to $FeSO_4$.

$$\therefore \text{Weight of outlet liquor } (l) = L + W_d + 0{\cdot}551BT - 100DT \quad ...(4)$$

The proportion of H_2SO_4 in the outlet liquor is, by definition

$$\frac{LA/100 - BT - DAT}{L + W_d + 0{\cdot}551BT - 100DT} = \frac{a}{100}$$

$$\therefore L = [100(BT + DAT) + a(W_d + 0{\cdot}551BT - 100DT)]/(A - a) \quad ...(5)$$

and by substituting in equation (4),

$$l = [100BT + A(W_d + 0{\cdot}551BT)]/(A - a) \quad ...(6)$$

Since the amount of ferrous sulphate in the outlet liquor is, by definition, $lf/100$ and since from equation (2) this is $LF/100 + 1{\cdot}551BT - DFT$, it follows that

$$F = (lf - 155{\cdot}1BT)/(L - 100DT) \quad ..... \quad (7)$$

The inlet and outlet liquor rates and ferrous sulphate concentrations depend, therefore, on the amount of acid consumed in pickling, on the amount of dilution, and on the difference between the inlet and outlet acid strengths. Also, the inlet-liquor rate varies with drag-out, whereas the outlet rate does not and, as is to be expected, the inlet and outlet ferrous sulphate concentrations are interdependent. While some of the factors in the above equations may be varied arbitrarily, it is essential that the liquor rates are such that the pipes connecting the tanks in the line are capable of taking the flow, that the outlet liquor is not saturated with ferrous sulphate so as to avoid crystallization in the tanks, and that the pickle liquor is active enough to de-scale the strip satisfactorily.

The value of W_d is difficult to assess without a knowledge of a large number of facts. It is best to measure the inlet and outlet flow-rates, in lb./hr., on a similar line pickling the same material and to use the relationship $l - L = W_d + T(0{\cdot}551B - 100D)$, (*see* equation (4)), and so evaluate W_d. Alternatively, a knowledge of the steam fed in to maintain tank temperatures and of the amount of water vapour lost by evaporation would give a similar estimate. If submerged steam-coils are used for heating, W_d will almost certainly be negative.

ACID RECOVERY

If pickling conditions are chosen such that the above three conditions are satisfied, and if the unknowns are calculated, it is possible to decide the precise functions that an acid recovery system has to perform. In one hour it must convert l lb. of liquor containing $a\%$ H_2SO_4, and $f\%$ $FeSO_4$ into L lb. containing $A\%$ H_2SO_4 and $F\%$ $FeSO_4$. To do this,

ferrous sulphate is crystallized from the spent liquor and removed by filtration or centrifuging and B.O.V. added either before or after crystallization and removal. The crystallization can be effected in two ways, namely, by cooling the liquor to obtain copperas or by evaporating the liquor to acid strengths at which the monohydrate is deposited. The acid strengths of the mother liquors produced by the second method necessitate the re-addition of some, at least, of the water boiled off. The weight of ferrous sulphate to be removed is that produced in pickling less that lost in drag-out, and the weight of B.O.V. to be added is equivalent to that consumed in pickling and lost in drag-out. Since the acid recovery system and the pickling line must be integrated, it is essential that there be no build-up or loss of water in the circuit. In other words, the weight of liquor after the removal of ferrous sulphate and the addition of B.O.V. must be equal to L. If it is greater than L, water must be removed by evaporation, preferably before crystallization, whilst if it is less than L, water must be added, preferably after ferrous sulphate removal.

Since it is possible to add the B.O.V. either before or after the removal of the ferrous sulphate and since also the ferrous sulphate may be produced in the form of copperas or monohydrate, the following four methods of treatment must be considered :

(1) B.O.V. added before crystallization of copperas
(2) B.O.V. added before crystallization of monohydrate
(3) B.O.V. added after removal of copperas
(4) B.O.V. added after removal of monohydrate.

The following additional notation is employed in this section :

w' = water to be removed or added to restore the water balance when copperas is crystallized
w'' = water to be removed or added to restore the water balance when monohydrate is crystallized
W_a = water to be removed, when w' or w'' is positive, to ensure that the correct amount of ferrous sulphate is crystallized
W_b = water to be removed, when w' or w'' is negative, to ensure that the correct amount of ferrous sulphate is crystallized
C' = [H_2SO_4] in liquor from crystallizer after the removal of W_a or W_b when copperas is crystallized
C'' = [H_2SO_4] in liquor from crystallizer after the removal of W_a or W_b when monohydrate is crystallized.

Method I—Addition of B.O.V. before Cooling to Crystallize Copperas

The amount of copperas to be crystallized is $2{\cdot}837BT - 1{\cdot}829DFT$ and the amount of B.O.V. to be added is $1{\cdot}282(BT + DAT)$, where

2·837 is the conversion factor for H_2SO_4 to $FeSO_4.7H_2O$,

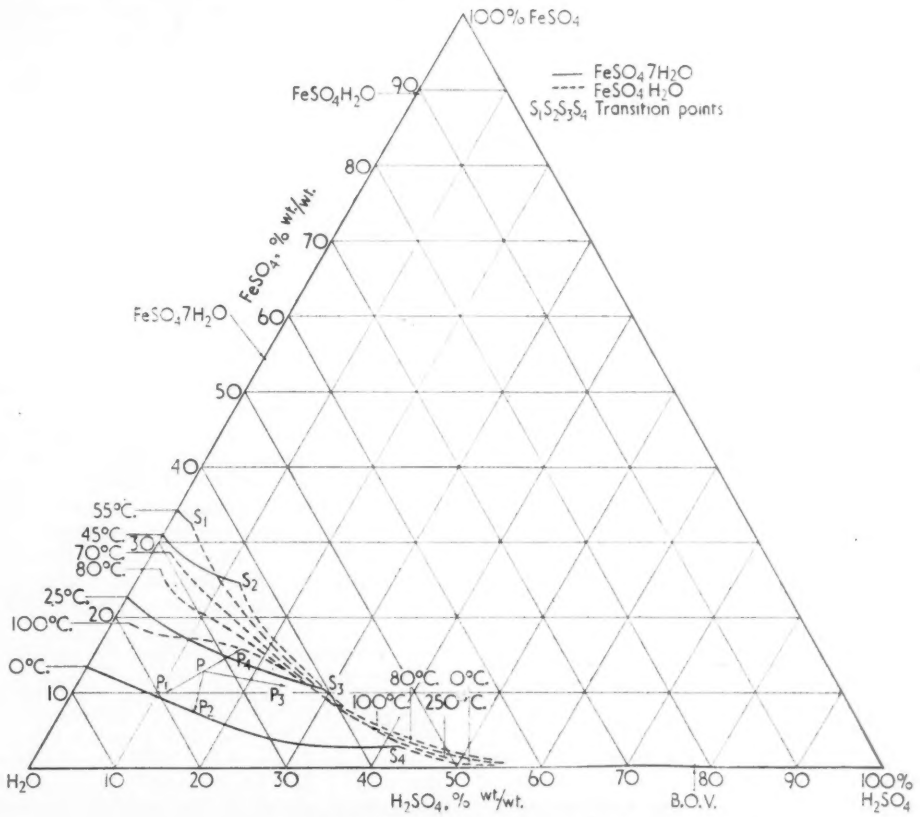

Fig. 2—$FeSO_4$–H_2SO_4–H_2O ternary diagram

1·829 is the conversion factor for $FeSO_4$ to $FeSO_4.7H_2O$, and
1·282 is the conversion factor for H_2SO_4 to B.O.V.

After the addition of the B.O.V. and removal of copperas, the liquor would be $l + 1{\cdot}282\ (BT + DAT) - (2{\cdot}837BT - 1{\cdot}829DFT)$, but since the liquor actually entering the tanks must be L,

$$w' = l + 1{\cdot}282(BT + DAT) - (2{\cdot}837BT - 1{\cdot}829DFT) - L,$$

and since

$$l - L = W_d + 0{\cdot}551BT - 100DT \text{ (see equation 4)},$$

$$w' = W_d - T[1{\cdot}004B + D\ (100 - 1{\cdot}829F - 1{\cdot}282A)] \quad \ldots(8)$$

(a) w' positive—w' must be boiled off before adding the B.O.V. Before it is boiled off $[H_2SO_4]$ is a and $[FeSO_4]$ is f. After w' is removed,

$$[H_2SO_4] = la/(l - w') \quad \ldots(9)$$

$$\text{and } [FeSO_4] = lf/(l - w') \quad \ldots(10)$$

If these concentrations correspond to a supersaturated condition at the evaporating temperature, crystallization may occur in the evaporator and the problem should be tackled by the monohydrate method given later.

If the solution is undersaturated, then $1{\cdot}282(BT + DAT)$ B.O.V. must be added and the mixture cooled until the mother liquor has $[H_2SO_4] = A$, and $[FeSO_4] = F$. The requisite temperature can be found from the ternary diagram (Fig. 2) as the isothermal on which lies the point A ; F. To avoid deposition of monohydrate on adding the B.O.V., it may be necessary to cool the liquor a little before adding the acid. It is possible that even with this precaution, the acid strength of the solution will be such that monohydrate is deposited and the above considerations will not then be valid.

If the requisite cooling temperature is inconveniently low, more water (W_a) must be evaporated to increase $[H_2SO_4]$ and thus depress the solubility of $FeSO_4$, allowing the correct amount of copperas to crystallize at a higher temperature. The B.O.V. must then be added and the liquor cooled. After W_a is evaporated, the B.O.V. added, and the copperas crystallized, the liquor is $L - W_a$ and it contains $LA/100$ H_2SO_4 ; $[H_2SO_4]$ is therefore $LA/(L - W_a)$. If at the convenient cooling temperature, C' is the acid strength at which the mother liquor has an $H_2SO_4/FeSO_4$ ratio of A/F (as read from the ternary diagram), then

$$C' = LA/(L - W_a) \text{ and}$$

$$W_a = L - LA/C' \quad \ldots(11)$$

After this secondary evaporation and before the B.O.V. has been added and the copperas crystallized, $[H_2SO_4]$ and $[FeSO_4]$ are respectively $la/(l - w' - W_a)$ and $lf/(l - w' - W_a)$. If these correspond to supersaturation in the evaporator, crystallization may occur and the problem still requires to be treated by the monohydrate method. If the solution is undersaturated, addition of $1{\cdot}282(BT + DAT)$ B.O.V., followed by cooling to the chosen convenient temperature will deposit the correct amount of copperas and, after filtration and addition of an amount W_a of water to the mother liquor, the system will be in balance. The remarks made earlier about the effect of high acid strengths causing deposition of monohydrate apply here also.

(b) w' negative—When w' is negative, it means that water has to be added to restore the water balance. It is better to add it after the removal of the copperas, otherwise it will dilute the solution and will make crystallization less efficient. The liquor after B.O.V. addition and copperas removal is $L - w'$, $[H_2SO_4]$ is $LA/(L - w')$, and $[FeSO_4]$ is $LF/(L - w')$. In this instance, therefore, $1{\cdot}282(BT + DAT)$ B.O.V. is added to the spent liquor and the mixture cooled until the mother liquor has the $[H_2SO_4]$ and $[FeSO_4]$ given above. This temperature can be read from the ternary diagram. After filtration and addition of w' to the mother liquor the system will be in balance. As in the case of w' positive, it is essential that the addition of the B.O.V. should not make the acid strength so high that monohydrate is deposited.

If the necessary cooling temperature is inconveniently low, the solution must be evaporated to remove water (W_b), the B.O.V. added, and the liquor cooled. W_b will be $W_a - w'$, *i.e.*,

$$W_b = L - LA/C' - w' \quad \ldots(12)$$

After this evaporation, the weight of the liquor is $l - W_b$ and $[H_2SO_4]$ and $[FeSO_4]$ are thus $la/(l - W_b)$ and $lf/(l - W_b)$, respectively. If these correspond to supersaturation in the evaporator the problem requires to be treated by the monohydrate method. If the solution is undersaturated, addition of $1{\cdot}282(BT + DAT)$ B.O.V. followed by cooling to the chosen temperature will deposit the correct amount of copperas and after filtration and addition of $W_b + w'$ water to the mother liquor, the system will be in balance.

Method II—Addition of B.O.V. before Crystallization of Monohydrate

B.O.V. is added to the spent liquor which is then evaporated to crystallize the monohydrate. The $FeSO_4.H_2O$ to be removed is $1{\cdot}735BT - 1{\cdot}118DFT$, where

1·735 is the conversion factor for H_2SO_4 to $FeSO_4.H_2O$, and
1·118 is the conversion factor for $FeSO_4$ to $FeSO_4.H_2O$.

After the addition of $1{\cdot}282(BT + DAT)$ B.O.V. and the assumed removal of the monohydrate, the liquor is $l + 1{\cdot}282(BT + DAT) - (1{\cdot}735BT - 1{\cdot}118DFT)$. Since, as before, the liquor entering the tanks is L,

$$w'' = l + 1{\cdot}282(BT + DAT) - (1{\cdot}735BT - 1{\cdot}118DFT) - L.$$

Eliminating $l - L$ by equation (4)

$$w'' = W_d - T[D(100 - 1{\cdot}118F - 1{\cdot}282A) - 0{\cdot}098B] \ldots(13)$$

(a) w'' positive—After boiling off w'', the liquor needs further boiling to remove W_a so that $H_2SO_4/FeSO_4$ in the mother liquor is A/F. By analogy with Method I*a*,

$$W_a = L - LA/C'' \quad \ldots(14)$$

where C'' is the acid strength at the evaporating temperature at which the mother liquor has an $H_2SO_4/FeSO_4$ ratio of A/F.

During this evaporation, monohydrate deposition takes place and when the filtered liquor is returned to the tanks together with a weight of water W_a the system is in balance.

(*b*) w'' **negative**—As in Method I*b*, when w'' is negative, the water is added after the removal of the ferrous sulphate. The amount of water to be removed after the addition of the B.O.V. so that the correct amount of monohydrate will deposit is $W_a - w''$, *i.e.*,

$$W_b = L - LA/C'' - w'' \quad \text{.....(15)}$$

After removing the monohydrate, the mother liquor is returned to the tanks together with a weight of water $W_b + w''$ and the system will be in balance.

Method III—Addition of B.O.V. to the Mother Liquor after the Removal of Copperas

The amount of water to be removed to restore the water balance does not depend on the point at which the B.O.V. is added, but is the difference between (l + B.O.V.) and (L + hydrated ferrous sulphate). In this method, therefore, w has the same value as in Method I, *i.e.*,

$$w' = W_d - T[1{\cdot}004B + D(100 - 1{\cdot}829F - 1{\cdot}282A)]$$

(*a*) w' **positive**—As in Method I, $[H_2SO_4]$ and $[FeSO_4]$ after removing w' are $la/(l - w')$ and $lf/(l - w')$, respectively. If these correspond to supersaturation in the evaporator, the problem must be tackled by Method IV.

If the solution is undersaturated, it must be cooled until the mother liquor has a composition such that, after addition of $1{\cdot}282(BT + DAT)$ B.O.V., the acid and ferrous sulphate concentrations are A and F. The temperature to which cooling must be carried can be found from the ternary diagram—it is the isothermal on which lies the intersection of the line from the copperas point through the point $la/(l - w')$; $lf/(l - w')$ and the line from the B.O.V. point through the point A ; F.

If the necessary cooling temperature is inconveniently low, more water (W_a) must be removed and the solution cooled. After removing W_a and crystallizing the copperas, the weight of the liquor will be $L - W_a - 1{\cdot}282(BT + DAT)$ and it will contain $la/100H_2SO_4$ and $LF/100FeSO_4$. If at the convenient cooling temperature, the acid strength at which the mother liquor has the $H_2SO_4/FeSO_4$ ratio of la/LF is C',

$$C' = la/[L - W_a - 1{\cdot}282(BT + DAT)]$$
$$\text{and } W_a = L - la/C' - 1{\cdot}282(BT + DAT) \quad \text{.....(16)}$$

After removing W_a, but before the copperas crystallizes, the liquor is $l - w' - W_a$ and

$$[H_2SO_4] = la/(l - w' - W_a) \quad \text{.....(17)}$$
$$\text{and } [FeSO_4] = lf/(l - w' - W_a) \quad \text{.....(18)}$$

If equations (17) and (18) correspond to supersaturation in the evaporator, crystallization of monohydrate may occur and the monohydrate method (Method IV) should be employed. If the solution is undersaturated, cooling to the chosen temperature will deposit copperas and the system will be in balance after filtration and after the addition of W_a and the B.O.V.

(*b*) w' **negative**—As in Methods I*b* and II*b*, w' has to be added after the copperas has been removed. The liquor must be cooled until the mother liquor has a composition such that the addition of $1{\cdot}282(BT + DAT)$ B.O.V. and w', will restore the acid and ferrous sulphate concentrations to A and F. The necessary cooling temperature is found from the ternary diagram and is the isothermal on which lies the intersection of the line from the copperas point through the point a ; f and the line from the point $100BT/[1{\cdot}282(BT + DAT) + w']\%$ H_2SO_4 ; 0% $FeSO_4$ through the point A ; F.

If the necessary cooling temperature is inconveniently low, more water must be removed and the solution cooled. This water will have a weight

$$W_b = L - la/C' - 1{\cdot}282(BT + DAT) - w' \quad \text{...(19)}$$

where C' is, as in Method III*a*, the acid strength at which the $H_2SO_4/FeSO_4$ ratio in the mother liquor is la/LF. After removing this water

$$[H_2SO_4] = la/(l - W_b) \quad \text{.....(20)}$$
$$\text{and } [FeSO_4] = lf/(l - W_b) \quad \text{.....(21)}$$

The concentrations (20) and (21) must not correspond to supersaturation. If the solution is undersaturated, cooling to the chosen temperature will deposit the correct amount of copperas and after adding water ($W_b + w'$) and the B.O.V., the system will be in balance.

Method IV—Addition of B.O.V. to the Mother Liquor after the Removal of Monohydrate

The amount of water removed to restore the water balance will be the same as in Method II, *i.e.*,

$$w'' = W_d - T[D(100 - 1{\cdot}118F - 1{\cdot}282A) - 0{\cdot}098B]$$

(*a*) w'' **positive**—More water requires to be removed and, by analogy with Method III, this will obviously be given by

$$W_a = L - la/C'' - 1{\cdot}282(BT + DAT) \quad \text{.....(22)}$$

where C'' is the acid strength at the evaporating temperature at which the mother liquor has the $H_2SO_4/FeSO_4$ ratio of la/LF. After removing the monohydrate, addition of a weight of water W_a and $1{\cdot}282(BT + DAT)$ B.O.V. will bring the system back to balance.

(*b*) w'' **negative**—As before, w'' is added after the monohydrate removal. The extra water to be removed is

$$W_b = L - la/C'' - 1{\cdot}282(BT + DAT) - w'' \quad \text{...(23)}$$

After removing the monohydrate, the addition of $W_b + w''$ of water and the B.O.V., will restore the system to balance.

Numerical Example

In this example, it is assumed that $A = 25$, $a = 15$, $f = 15$, $W_d = 2000$, $D = 0{\cdot}2$, $B = 20$, and $T = 70$.

From equation (5),

$$L = [100(BT + DAT) + a(W_d + 0{\cdot}551BT - 100DT)]/(A - a) = 19{,}555 \text{ lb.}$$

From equation (4),

$$l = L + W_d + 0{\cdot}551BT - 100DT = 20{,}925 \text{ lb.}$$

From equation (6),

$$F = (fl - 155{\cdot}1BT)/(L - 100DT) = 5{\cdot}33\%$$

Method I

$w' = W_d - T[1{\cdot}004B + D(100 - 1{\cdot}829F - 1{\cdot}282A)]$
$= -219{\cdot}7$ lb./hr.

As w' is negative, Method I*b* must be employed. The water (219·7 lb.) is therefore added after the separation of the copperas. $1{\cdot}282(BT + DAT)$ lb. of B.O.V. (= 2240 lb.) are added per hour and the solution cooled until the mother liquor has a composition of $LA/(L - w')\%$ H_2SO_4 ($19{,}555 \times 25/(19{,}555 - 219{\cdot}7) = 25{\cdot}29\%$) and $LF/(L - w')\%$ $FeSO_4$ (= 5·39%). This composition lies on the 5° C. isothermal. Therefore, on adding B.O.V. at the rate given above, cooling to 5° C., filtering the copperas, and adding water at the rate of 219·7 lb./hr., the system will be in balance.

This temperature may be inconveniently low, so water (W_b) must be boiled off before the B.O.V. addition, and the liquor then cooled down to the convenient cooling temperature, say 20° C. A line from the H_2O point of the ternary diagram through the point 25% H_2SO_4 ; 5·3% $FeSO_4$ cuts the 20° C. isothermal at $[H_2SO_4] = 34{\cdot}4\%$. The value of C' is thus 34·4%. At this acid strength the solid in equilibrium with the mother liquor is the monohydrate. Therefore, unless it is possible to cool to below 20° C., say 10° C. or lower, it will not be possible to crystallize copperas.

Carrying out the calculations indicated in Method I*b* shows that after boiling off $W_b(L - w' - LA/C' = 4935)$ lb., the liquor will have a composition of $la/(l - W_b)$ and $lf/(l - W_b)$, *i.e.*, 19·6% H_2SO_4 and 19·6% $FeSO_4$. This is a supersaturated solution at any temperature (*see* Fig. 2) and monohydrate will crystallize in the evaporator. Only if it is possible to cool to below 10° C. can Method I be used.

Method II

$w'' = W_d - T[D(100 - 1{\cdot}118F - 1{\cdot}282A) - 0{\cdot}098B]$
$= 1270$ lb./hr.

Method II*a* must therefore be used.

At an assumed evaporating temperature of 100° C., $C'' = 34{\cdot}4\%$, *i.e.*, a line through the point A ; F from the H_2O point cuts the 100° C. isothermal at this value. The coincidence of this value with that for C' occurs because at high acid strengths the solubility of ferrous sulphate is only very slightly affected by temperature. After water has been boiled off at the rate of $(w'' + W_a)$ lb./hr. $= w'' + L - LA/C'' = 1270 + 5345$ lb./hr., B.O.V. added at the rate of 2240 lb./hr., the monohydrate removed, and water re-added at the rate of 5345 lb./hr., the system will be in balance.

Method III

As in Method I, $w' = -219{\cdot}7$ lb. The copperas must therefore be removed after cooling and the B.O.V. and 219·7 lb. of water added. The temperature to which cooling must be carried is given by the isothermal on which lies the intersection of the line from the copperas point through a ; f (*i.e.*, 15 ; 15) and the line from $100BT[1{\cdot}282(BT + DAT) + w']\%$ H_2SO_4; 0% $FeSO_4$ (*i.e.*, 56·9; 0) through the point A ; F (*i.e.*, 25 ; 5·33). The intersection (18·2 ; 6·6) lies on the 0° C. isothermal. It is necessary, therefore, to cool to 0° C.

This temperature is probably inconveniently low, so that more water (W_b) must be boiled off before cooling to the assumed convenient temperature of 20° C. W_b is given by the expression $L - w' - 1{\cdot}282(BT + DAT) - la/C'$, where C' is the acid strength at 20° C., at which $H_2SO_4/FeSO_4$ is la/LF (= 3·02). C' is therefore 29% and W_b equals 6285 lb./hr.

The concentrations after this water removal will be $la/(l - W_b)\%$ H_2SO_4 and $lf/(l - W_b)\%$ $FeSO_4$, *i.e.*, 21·4 ; 21·4. This is a supersaturated solution at all temperatures, and monohydrate would be deposited in the evaporator.

Method IV

As in Method II, $w'' = 1270$ lb./hr. Since, as shown above, $la/LF = 3{\cdot}02$, C'' at an assumed evaporating temperature of 100° C. is 29·6%.

$\therefore W_a = L - 1{\cdot}282(BT + DAT) - la/C''$
$= 6711$ lb./hr.

After 1270 + 6711 = 7981 lb./hr. have been boiled off, the correct amount of monohydrate will have deposited and after filtration and addition of 2240 lb. of B.O.V. and 6711 lb. of water/hr., the system will be in balance.

Conclusions

Methods I and III, *i.e.*, crystallizing copperas will work only if it is possible to cool to temperatures of about 0–5° C. although a different result might have been obtained if different pickling conditions had been assumed. Method II requires that a total of 6615 lb. of water be evaporated per hour of which 5345 lb. are re-added, and Method IV requires a total evaporation of 7981 lb. and a re-addition of 6711 lb. of water/hr. It is important to note that Methods II and IV can always be arranged to work but Methods I and III may be impossible if adequate cooling temperatures cannot be reached.

APPENDIX

Solubility of Ferrous Sulphate in Sulphuric Acid–Water Mixtures

The calculations in the preceding section depend upon an accurate knowledge of the solubility of ferrous sulphate in sulphuric acid solutions at various temperatures. Other investigators, notably Fraenckel[4]

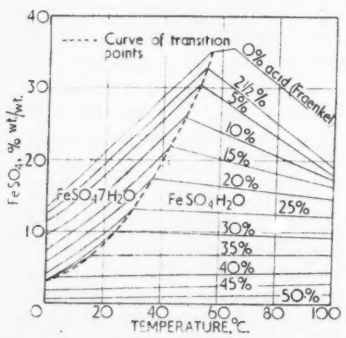

Fig. 3—Solubility of ferrous sulphate as a function of temperature and sulphuric acid concentration. Acid concentration is in % wt./wt.

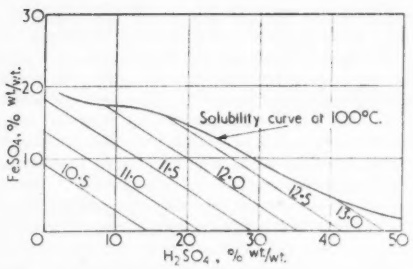

Fig. 4—Density (lb./gal.) of solutions of ferrous sulphate in sulphuric acid at 100° C.

and Cameron,[5] have determined solubilities at and below 90° C. Since pickling baths and evaporating equipment often function above this temperature, solubilities have been determined at 100° C. and as there appears to be some disagreement among published results, the authors have also re-determined values at 0°, 25°, 45°, 55°, 70°, and 80° C. It is hoped later to publish in detail the methods employed and the results obtained, but in order that the present paper may be used as intended, the results are given in graphical form. Figure 3 shows that, at a fixed temperature, the solubility decreases with increase in acidity and, at a constant acidity, it increases with temperature up to a transition point and then decreases. The deposition of monohydrate from solutions of low acid strength and high temperature can be very slow, giving an apparently abnormal solubility.

As indicated in the section on acid recovery, it is more convenient if solubilities are plotted as isothermals on a ternary diagram as in Fig. 2, which shows which phase—heptahydrate or monohydrate—is in equilibrium with the solution in question. With the aid of this diagram the change in composition of a solution when subjected to various treatments may be followed. For example, if a solution represented by the point P is

(*a*) diluted with water, then the composition follows line PP_1, *i.e.*, towards the H_2O point

(*b*) cooled to crystallize copperas, then the mother liquor composition follows the line PP_2, *i.e.*, away from the copperas point

(*c*) treated with B.O.V., then the composition follows the line PP_3, *i.e.*, towards the B.O.V. point, until it meets its appropriate isothermal when ferrous sulphate is precipitated and the mother liquor follows the isothermal towards the right

(*d*) evaporated, then the composition follows the line PP_4, *i.e.*, away from the H_2O point until, as in (*c*) it meets its appropriate isothermal. Ferrous sulphate is then deposited and the composition of the mother liquor follows this isothermal towards the right.

Density of Undersaturated Solutions of $FeSO_4$ in H_2SO_4–Water Mixture

Inlet and outlet flow rates are more conveniently expressed in terms of volume per hour than in terms of weight per hour, as used in this report, but conversion may be made if the density of the liquor is known. Since the only published data refer to temperatures of 15° and 55° C.,[2] the densities of undersaturated solutions were determined at 80° and 100° C. The results at 100° C., together with the appropriate solubility curve, are shown in Fig. 4, as lines of constant density. There is an approximately linear relationship between the concentrations of H_2SO_4 and $FeSO_4$ at a constant density, and density decreases fairly regularly with dilution. Similar density lines were obtained at 80° C.; the density of a particular solution was, of course, slightly higher than at 100° C. From these approximate relationships it is possible to derive a simple equation involving composition, temperature, and density. This takes the form :

$$[FeSO_4] + 0{\cdot}635\,[H_2SO_4] + 85{\cdot}1 - 0{\cdot}065t = 8{\cdot}44d$$

where

$[FeSO_4]$ is the concentration of $FeSO_4$ in % wt./wt.
$[H_2SO_4]$ is the concentration of H_2SO_4 in % wt./wt.
t is the temperature in ° C.
d is the density in lb./gal.

This equation is accurate for solutions of medium acid and ferrous sulphate concentrations at the higher temperatures but the accuracy falls off by about 1% for solutions of low temperature or of high acid or ferrous sulphate content.

Acknowledgments

The authors thank Mr. W. C. F. Hessenberg, Head of the Mechanical Working Division of B.I.S.R.A., for his helpful advice, and Mr. T. A. Canning for carrying out the determinations of solubility and specific gravity.

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THE UNIT OF HEAT

In a pamphlet entitled " The Unit of Heat," issued by the Royal Society in October, 1950, it is recommended that quantities of heat, and all other dependent concepts, should in future be expressed both in joules and in calories.

A memorandum by Sir Charles Darwin is printed below. The Editor would be glad to have readers' views on whether or not the proposal should be adopted for use in the Institute's publications.

MEMORANDUM ON THE UNIT OF HEAT

By Sir Charles Darwin, F.R.S.

It has recently been agreed by all the important international bodies concerned that the joule, of 10^7 ergs, is to be the *basic* unit of heat. This is a decided matter, and there can be no doubt of the correctness of the decision. The reasons are briefly as follows.

The First Law of Thermodynamics states that heat is energy, and it is therefore proper that it should be measured in the same units as energy, that is the joule. Hitherto the unit has been the calorie, which was chosen rather arbitrarily more than a century ago for its practical convenience, because the early work in calorimetry was mostly done by observing the change of temperature of a water bath. Thus the calorie involved the idea of temperature which is quite irrelevant to the First Law, and it also had reference to an arbitrarily chosen specific substance, water. To use the calorie it was thus necessary to have a number, the mechanical equivalent of heat, which masqueraded as a universal physical constant, though in fact it is nothing but the specific heat of water measured in energy units.

The next point to note is that there are quite a number of different calories in use, differing perceptibly in magnitude, and so making a lot of confusion. The most usual is perhaps (1) the 15° calorie (from 14½° to 15½°), and very nearly but not quite equal to (2) the International Steam Table calorie. Then there is (3) the 4° calorie (which has the advantage of giving the specific heat at constant volume, since it is at the point of maximum density of water), (4) the Thermochemical or 'Defined' calorie, and (5) the Mean calorie (from 0° to 100°). The differences between these range over one part in two hundred. There has also in the past been a minor source of confusion because some writers used the term calorie for the 'Great Calorie,' (of a kilogramme instead of a gramme); this should be, and now usually is, called the kilocalorie.

There is a very similar state of confusion over the British Thermal Unit, based on the pound of water, and the degree Fahrenheit, where there are four slightly discrepant definitions also. There has also been defined the quite different unit of the 'pound-calorie,' using the centigrade scale, but this has had little vogue and need not be considered. The B.Th.U. happens to be only about 5% different from the kilojoule.

Most calorimetric work has no very high accuracy, and in such work these differences between the calories have no importance. Work of high precision is now practically always done by electrical heating, and the heat is measured by the product of the volts and amperes used and the seconds of time for which the current flows. The mechanical equivalents of the electrical units are known to an accuracy far beyond that attainable in any calorimetric work, so that the results are given automatically directly in joules. To express these results in calories it is necessary to choose arbitrarily one among the variously defined calories and multiply by the appropriate factor.

It must be recognized that the replacement of the calorie by the joule would have effects far outside pure calorimetry, and would have wide repercussions in the whole field of physical chemistry. It would affect not only specific heat, latent heat, and heat of combustion, but also entropy, internal energy, enthalpy, free energy, Gibbs function, and thermal conductivity. It may be noticed that for some of these the work is often not calorimetric; for instance, many free energies are determined by the voltage of an electrolytic cell, so that here again the determination would be more naturally done directly in joules.

The fact that the joule is the basic unit does not necessarily imply that it has got to be used in actual practice, but it would be the natural thing to do, and, as has been said, there are a good many cases where it is the quantity actually determined by experiment. The theoretical advantages are overwhelmingly in its favour, but the contrary arguments must also be considered.

The only really strong argument against it is that it is always inconvenient to make any change of units. Nearly all work in the past has been expressed in calories, and the numerical values, if now given in joules, will be unfamiliar to most people. The process would have the same sort of inconvenience as that of converting British units of mass and length into metric, but it would be far less troublesome, because there is only a single multiplying factor, instead of complicated products of various powers of mass and length, which are needed for the various mechanical quantities. However, this point cannot be invoked as an argument in favour of the joule, since we are forced to convert from British to metric system in order to be comprehensible to foreigners, whereas the calorie is as much used abroad as at home.

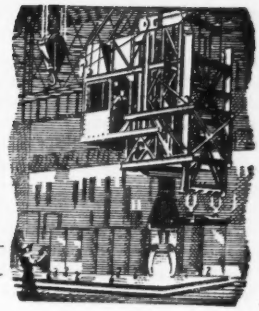
If the line is taken that the change to the practical use of the joule is too inconvenient to be considered, there is still to be faced the variety among the different calories. In the present instructions given by the International Unions of Physics and Chemistry it is laid down that, where values are given in calories, the conversion factor to joules is always to be stated. This makes a formally self-consistent system, but it is certainly not convenient. A better solution on these lines might be to select a particular value, and define the calorie as, say, exactly 4·187 joules. A difficulty about such a proposal is that it would have to be agreed first by the leading workers (some of whom have vested interests in particular values) and then by the International Unions, and to judge by past experience it might easily take ten years before such agreement would be reached. And in the end after all this we should be left with a unit that was meaningless. Moreover, as pointed out above, much work in fact comes out directly in joules and would have to be converted from the correct into the meaningless unit.

It is here contended that as some reform is necessary, it had better be the full reform. Most people naturally fear a change of units, but the fear is exaggerated, as witness the speed with which we can get used to foreign currencies when we are abroad. The present conversion is one of the simplest possible, far simpler than the change from British units to metric, since it involves only one instead of a multiplicity of factors.

The aim of the present proposal is to get the joule into common use in numerical work with as little inconvenience as possible. It is proposed that where the numerical value of a thermodynamic quantity is given in a scientific paper it should be given in joules, kilojoules, etc., but that the author may give the value in calories in parenthesis afterwards as well. This is somewhat parallel to the method of giving metric equivalents to British mechanical units, which is used in some journals. The proposal recognizes that there are at present few who really think in terms of joules, so that it is important that the reader should be helped by also seeing quantities in familiar form. On the other hand, it must be recognized that, unless some drive is put into getting people accustomed to the joule, it will never get into use at all, and we shall be left either with the present confused system, or else with an arbitrary unnatural unit, the only merit of which is that of tradition. It is suggested that the Royal Society is the appropriate body to provide the drive in favour of the correct unit.

As to the field over which the proposal should apply, it is intended to be only for strictly scientific work, where there is likely to be little effect on the general public. For example, it is to be presumed that the B.Th.U. will continue to be used in the sale of gas or coal and for the more practical studies of fuels. Again, the use of the calorie by dietitians has got into the public consciousness, and it would be inadvisable to change it. Other similar cases may arise.

IRON AND STEELWORKS ENGINEERING



THE IRON AND STEEL ENGINEERS GROUP

THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE THIRTEENTH MEETING

THE THIRTEENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 28th June, 1950. Mr. C. H. T. WILLIAMS, Chairman of the Group, was in the Chair.

The MORNING SESSION was devoted to the presentation and discussion of the two papers: "Heating and Ventilation in the Iron and Steel Industry," by F. R. L. White (Brightside Foundry and Engineering Co., Ltd.), and "Lighting in Iron and Steel Works," by G. W. Levey (McLellan and Partners).

The AFTERNOON SESSION was devoted to the presentation and discussion of the paper: "The Supply and Distribution of Water to Iron and Steel Works," by J. L. Daniel (Stewarts and Lloyds, Ltd.). The discussion on the first paper is given below. That on the second paper and on the paper by Mr. Daniel will be published in the May issue of the *Journal* (vol. 168).

PROCEEDINGS OF PART OF THE MORNING SESSION

Discussion on the Paper—
HEATING AND VENTILATION IN THE IRON AND STEEL INDUSTRY*

The **Chairman** (Mr. **C. H. T. Williams**): Four years ago last March, the Council of the Institute decided to form a Group to cover the general interests and activities of engineers within the industry, and to encourage discussions between the people who supply equipment to the industry and the people who use the equipment. Twelve meetings have been held, at which a great many subjects have been discussed. Mr. W. F. Cartwright has been the Chairman of the Organizing Committee, and I should like to record our appreciation of the excellent work that he and the members of the Committee have done during those four years.

The Organizing Committee has prepared a list of many subjects for discussion in the next two or three years; they would, however, welcome suggestions from members regarding other subjects. I ask you, therefore, to send in to the Secretary any suggestions that you may wish to make.

Mr. **F. R. L. White** (The Brightside Foundry and Engineering Co., Ltd.) briefly introduced his paper.

Mr. **H. Woods** (H.M. Factory Inspectorate): The author mentioned that if, in foundries, exhaust ventilation is applied to many processes, a very severe heat loss occurs. In a large number of operations, no attempt is made to introduce a fresh supply of air from the outside to feed the exhaust system and prevent the intake of air from the heated shop.

For example, it is common practice in a foundry for the exhaust of a rumbling barrel to be taken through a trunnion at one end of the machine, while the air to feed the exhaust is taken through the opposite trunnion. I think it would be quite easy to feed air, by a pipe, from the outside to this trunnion, and thus reduce heat loss. Also, the air which feeds the exhaust at grinding wheels is almost invariably taken from the shop; a supply of air taken directly from the outside would again reduce the heat loss from the shop. I understand that some experimental work has already been done, and I consider that these methods might be applied further, as, I gather, has been done in Sweden, if investigations were continued.

If a large volume of air is fed at a high rate to an exhaust fan close to an operator, he is subjected, particularly if he is working at a booth, to a very high rate of air movement past his body, which may make him feel very uncomfortable. This might be prevented by leading air from the outside in front of the working position of the operator.

I have seen few foundries in which plenum systems, involving long lengths of ducting, are in use. The chief objection to the installation of such plant is the large

* *Journal of the Iron and Steel Institute*, 1950, vol. 165, June, pp. 221–226.

number of obstructions, such as overhead cranes, service pipes, etc., which makes it difficult to accommodate the ducting. There has therefore been a tendency to modify the plenum system by introducing a coal-fired stove to heat a supply of air that is circulated round it, and that is then directed by fans over the required part of the shop.

Mr. White: The great difficulty in introducing cool air, particularly to grinding wheels, is that by decreasing the depression at the wheel by the introduction of a fresh supply of air, the pulling power that is required for the entrainment of small grinding particles is reduced. There is a related value of velocity at which particles can be carried, and if the velocity is below this value, the carrying capacity of the air is reduced, and the particles are precipitated. Unless the depression caused at the face of the wheel is sufficient to entrain those particles, they fly out of the hood, because of the fan action of the stone, and more are deposited around the machine than are carried away.

It is preferable to circulate cold air than to allow warm air to pass outside; but I think any factory inspector would agree that to re-circulate air which had been once contaminated by dust would cause trouble immediately. Unless a filter which will remove particles and allow air to be re-circulated can be produced economically, a great deal of experimental work will have to be done to solve the problem.

The entrainment problem is not as difficult in regard to booths as it is in regard to grinding wheels. The operator works with his hands inside the booth, and dust is formed inside the hood, so that it is much easier to entrain the particles in the air stream. The velocity on the front face of a booth is considerably lower, and if the booth is correctly designed the flow of air should not cause too much discomfort.

In very old, low buildings, when considering the installation of the plenum system, the problem of obstruction can be rather serious. In modern buildings, however, obstructions should not seriously interfere, and I believe that plenum heating will be much more used in future industrial works.

Mr. F. A. Gray (The United Steel Companies, Ltd.): Would Mr. White tell us what is the difference between 'equivalent temperature' and 'effective temperature' in Dr. Bedford's table, and also how the degree of comfort is measured when using a radiant panel heating system?

In regard to the various types of heating system mentioned, I would be interested to know the relative costs of unit heaters, the plenum system, air conditioning, and the panel system, taking the cost of the unit heater as the standard. I believe that the fuel consumption of the panel heating system is low: would Mr. White say how it compares with the other systems?

The author has not mentioned the thermal insulation of buildings, apart from the reference in the list of points taken from the Garrett Report. There must be a great loss of heat from the structure of many buildings, particularly those with metal roofs, and I suggest that insulation should be seriously considered, especially when installing the heating system for a new plant. Could Mr. White say what saving in the cost of heating results from insulating the building, and also whether the reduced capital cost of the smaller heating plant which would be required would pay for the cost of insulation? Is insulation as effective in a high building as in a low one?

A major problem in the heating of buildings is that of door openings. How can this difficulty be resolved?

Mr. White: The equivalent temperature is measured by means of an instrument called a eupatheoscope, which is designed to simulate the human body. It is heated to a temperature of 75° F., and the rate of loss of heat from it gives an indication of air movement, and of the general thermal condition of the room. The equivalent temperature, which is roughly half-way between the temperatures of the surroundings, *i.e.*, between the mean radiant temperature and the air temperature, does not take humidity into account, whereas the effective temperature does. When the air temperature is 65° F., the average temperature of the surroundings, *i.e.*, the mean radiant temperature, may be as low as 55–60° F.

The degree of comfort, when using a panel heating system, is indicated by the mean radiant temperature. Generally, a person in a radiant-heated space at a certain temperature would be as comfortable as in a space heated by an ordinary convection system to a temperature 5° F. higher; this is because he would be receiving heat directly by radiation, irrespective of air movement.

It is rather difficult to give the relative costs of the different heating systems. Unit heaters would undoubtedly be the cheapest in capital outlay, but whether they would be cheapest in respect of maintenance is another matter, particularly in the iron and steel industry. The maintenance requirements of numbers of small units often rule out the unit heater system, especially if they are in such elevated positions that it is difficult to get to them. Often they fail through inattention, the motors burn out, and the batteries quickly become fouled. If the units are properly serviced, the system can be an economic one; otherwise, it can be very expensive.

Air-conditioning is costly in initial outlay, especially if refrigeration is necessary, as it might be when definitely controlled conditions are essential. The cost may well be twice as much as that of a unit heater system, and with a full refrigeration plant perhaps even more.

The cost of high-temperature panels varies, according to the type of building, from about 25% to 30% more than the cost of the unit heater system.

There is a saving in fuel with the radiant-heating system, in the sense that the 'comfort effect' of it, in relation to the effective temperature, is greater than with a convection system, although with a panel system it is also necessary to consider ventilation. With good natural ventilation the panel system is quite satisfactory, as, although the initial outlay is higher, there is a fuel saving of as much as 15% in some cases, and maintenance costs are at a minimum.

Clearly, if a building is insulated, fuel is saved. For example, with a corrugated-steel roof, the coefficient of transmission is about 1·4 B.Th.U./sq. ft./° F./hr., whereas if the roof is lined with insulating board this coefficient is about 0·32, and a saving of about three-quarters of the heat loss from the roof alone might be expected. If the walls, also, of a galvanized sheeted building are lined, there will be a further saving of fuel, the amount saved being dependent on the construction details. Insulation has the further advantage that in summer it keeps down the temperature within the building.

In regard to the insulation of high buildings, there are two opinions: (i) that the whole building must be considered, and (ii) that only the lower 15 ft. of the building need be considered. With a convection system, I would agree with the first opinion, but with a radiant system I agree with the second. With radiant heat, the convection factor is only a small proportion of the total heat and the amount of heat that goes into the roof spaces is therefore small. Convected heat is very difficult to control, because the air streams rise rapidly to the roofs.

Loss of heat through door openings is a real difficulty. To solve the problem, automatic air curtains have been

tried; when the door opens, a fan automatically starts up, and projects an air curtain over the doorway, preventing the incursion of air. Unless control is automatic, the method tends to be ineffective, because the operators will not trouble to switch on, and it is sometimes doubtful whether the automatic method justifies its high cost. The alternative is to employ air locks, but two sets of doors interfere with transport flow. I saw an attempt to deal with the doors problem at the Volkswagen works in Germany, where a cold air curtain was used, but a power consumption of about 30 h.p. per door was needed to maintain it.

Mr. T. Coxon (Consett Iron Co., Ltd.): I think in the iron and steel industry that the problem is one of cooling and ventilation rather than one of heating and ventilation. Buildings associated with iron and steel works are often some three million cu. ft. in extent, perhaps twice that amount if interconnected buildings are included, and this makes air conditioning by the plenum system out of the question. The air-conditioned cabin is being introduced for men working with hot metal, but for mills, steelworks, and blast-furnaces, where in relation to the size of the building the number of men is small, I think the only solution is to provide small air-conditioned rest rooms, and suitable clothing for the job.

Mr. White: Mr. Coxon's remarks emphasize my earlier statements about providing facilities for the men during their rest periods, a matter that has yet to be dealt with in works where very high temperatures exist. In some cases the radiant temperature may be as high as 250° F., and there is no hope of reducing it effectively by air douching. The only solution is to provide rest rooms for the men, in which the conditions are such that ill effects due to rapid change of environmental conditions are reduced to a minimum.

Mr. F. N. Bool (Park Gate Iron and Steel Co., Ltd.): Could Mr. White give us his views on the use of ozone generating equipment for the restoration of vitiated air? I believe it is extensively used.

Mr. White: An ozone plant does have some effect, but there are wide differences in medical opinion as to whether the ozonization of the air is a good thing or not. All I can say is that it can be very useful for deodorization.

Mr. J. L. Gaskell (Appleby-Frodingham Steel Co.): I am particularly interested in the extraction of heat from buildings housing electrical machinery; could the author comment on the relative merits or demerits of various types of filtering equipment? We have used the dry-bag type, but an alarming fire occurred on one occasion; on the other hand, the box-cell type of viscous filter requires continuous maintenance, and is subject to serious deterioration of the ferrules and to considerable clogging. At certain times, the box-cell filters were completely clogged in a few hours by large numbers of flies, which collected on the surface, making the filter virtually ineffective.

We have installed self-cleaning filters, but in those with strainer units, in which the oil is immediately re-circulated to the spray nozzles, the nozzles became clogged quickly. The system that we have now adopted is up to the present satisfactory. It consists of a dirty-oil tank which receives the oil from the self-cleaning filter; settlement takes place over about 24 hr., and the clarified oil is then pumped to a clean-oil tank, and passes through the spray nozzles on to the surface of the self-cleaning filter.

I have always been under the impression that the value of the heat equivalent of the human body at rest is about 100 W., and not 275 B.Th.U./hr., equivalent to 80 W., as given in the paper. The value of 1400–1900 B.Th.U./hr. (*i.e.*, 410–550 W.) mentioned in the paper for a man performing tasks, seems to be rather high, and I should like the author to state the source of his information.

Mr. White: The question of filters is a troublesome one. There is a trend now to use a wet type of filter, but it is not possible in some circumstances, for example, with electrical machinery, where it would be necessary to employ some form of adhesive filtering.

All methods of filtering are subject to criticism. Probably the most useful is the continuously self-cleaning type, in which the oil-bath receives the cells for cleaning at the rate of perhaps one or two a day. The atmosphere in a steelworks is probably one of the worst that exists, and if a filter is to be efficient in arresting the dust and particles, it must be cleaned. The question is what is the most economical and the most convenient form of cleaning, and though there is no perfect filter, I think that the self-cleaning type, of rotary pattern, is the most useful. A committee is now considering the question of filtration generally, and is trying to stipulate a standard test for filters so that an efficiency standard may be fixed.

Spray filters are quite useful for fettling and similar types of work, but they cannot deal with very heavy precipitations because the nozzles become clogged. It is possible to have a knife-edge filter in which the air is washed as it passes at a very high velocity under the plates. There is, however, a difficulty in that there is a large transference of moisture into the air, which comes off saturated, so that for many purposes it is unsuitable.

The figure of 275 B.Th.U./hr. for the equivalent heat of a body at rest is the absolute rate of basal metabolism; a body at 'normal' rest would dissipate about 350 B.Th.U./hr.

These figures are quoted from Dr. Bedford's works, as is also the value of 1400–1900 B.Th.U./hr. Incidentally, the heat loss from a body walking at 5 m.p.h. would be about 2300 B.Th.U./hr.

Mr. R. H. Holbeche (Institution of Heating and Ventilating Engineers): The problem in melting-shops, rolling mills, etc., is made difficult by the fact that temperature conditions vary widely over a relatively short time or distance. A man moves in the course of his job through a variety of temperatures, and some tasks can only be done for a very short time. The degree of physical effort entailed, the type of clothing worn, the length of exposure to radiant heat, and other factors which are involved, make generalizations difficult. The two main problems are the release of vast quantities of heat, difficult to remove before the ambient shop temperature is raised to an uncomfortably high level, and radiant heat.

The heat liberated by the plant is most effectively removed by the old-fashioned method of opening the sheeting of the side walls, and even removing alternate sheets from the roof, during summer. In old plants with low roofs, these, and well-designed jack-roofs, were the best remedies in peace-time conditions.

In modern plants, much more can be done, by having lofty and spacious buildings and by reducing the heat loss from furnaces by improved insulation and by water cooling of furnace doors, lintels, etc. Considerable economies in fuel consumption are achieved if this is done scientifically.

During the war it became necessary to enclose jack-roofs to reduce glare, and their ventilating efficiency was seriously impaired. This problem was tackled by mounting large-diameter propeller fans on the roofs, in light-obscuring cowls. I think it is surprising that steelworks do not make greater use of roof-mounted fans, as is done in the United States. It is true that a jack-roof

can move large quantities of air when the difference in temperature between the inside and the outside of a building is high, but it is not a very reliable method, since the rate of extraction fluctuates with the direction and strength of the wind and with the temperature difference. Also, the extraction rate is substantially lower in the summer, when the temperature difference and the wind velocity are at a minimum.

Fans work independently of the seasons or of the weather conditions, and their only disadvantages are that they consume power and require maintenance. The power consumption of a propeller fan is very low, however, and ball-bearing squirrel-cage fan motors of a reliable make require very little attention.

The best way of reducing the temperature of the radiating surfaces of furnaces is by insulation : this, however, can only apply to modern plants in which water-cooled floors have also been tried successfully. Such measures can be so effective that a modern melting shop may actually be too cold in winter.

It is shown in the Effective-Temperature Chart that air movement reduces the effective temperature and this is often the simplest way to improve working conditions. Unfortunately, the replacement air entering a shop as a result of the extraction of air through the roof is not easily controllable, and it will usually travel up to the roof from the side-wall entry points without penetrating any appreciable distance into the shop. To deliver air into the working areas, fans are needed, but it is often impossible to deliver outside air into working areas by means of ducts except into these areas close to an outside wall. Also, the presence of travelling cranes usually causes the ducts to be run above tie-bar level, and it is difficult to get them down to floor level again, because of the small clearance between the cranes in adjoining bays. How then can fans be applied ?

I would venture the opinion that the small air-douching nozzles to which Mr. White refers would be inadequate for the majority of steelworks, for which large volumes of slow-moving air, covering large areas, are needed. Propeller fans, mounted on the roof above crane level, have been tried for discharging air downwards into areas remote from the side walls, by means of suitably designed nozzles. Using 48-in. dia. fans, air was successfully pushed down from high roofs over melting-shops, casting pits, etc., and a head height velocity of about 200 ft./min. was provided.

Probably the most useful and versatile tool is the man-cooling fan, in which a high-velocity centre core of air entrains surrounding air, so that in the working area the total mass of air in motion is many times that of the initial output of the fan. The man-cooler is portable. One fan of well-known make, although only 19 in. in dia., has an effective range of 50 ft., and at distances of 40–50 ft. from the fan, the width or spread of the air beam is of the order of 15 ft. Within this area, the velocity of the air would be from 200–250 ft./min.

A man-cooling fan stirs only the interior shop air, but from the Effective-Temperature Chart, it can be seen that a substantial cooling effect is obtained from air movements of from 200–500 ft./min., although the air is at shop temperature. The use of cold outside air for cooling purposes introduces a risk of chills, and for this reason also, the discharge of high-velocity air from relatively small air-douche systems must be applied with care.

Cranes present a problem ; it is difficult to get fresh air into them because they are constantly in motion. Small crane-borne air-conditioning plants can, in this case, be useful.

Control cabins are another special problem, although it is often possible to get ducting into them from the roof. I used to enclose a space on top of the control cabin—a plenum chamber, as it were—over the whole length of the cabin, and introduce into this space a large volume of fresh air, by means of a propeller or axial-flow fan, usually 24–36 in. in dia., ducted through the roof. The normal ceiling of the cabin was replaced by pivoted sheet-metal slats, 6 in. wide, giving a venetian blind effect. The men inside the cabin could turn one or any number of slats to admit air from the plenum chamber, deflecting it downwards to suit their individual tastes.

Mr. **White** wrote in reply : Some of Mr. Holbeche's remarks raise fundamental issues which are controversial and cannot be considered adequately in the allotted space, but I will try to reply, as briefly as possible. The main sources of discomfort are excessive heat, dust, and fumes. I think it is far better to try to suppress these at their origin, rather than to provide gaping holes in a building to release them. If a large quantity of vitiated air is discharged, clearly it will have to be replaced by outside air, which may be at a temperature as low as 20–25° F., and this introduces health hazards. If more were done to improve production methods so far as heat and fume liberation are concerned, the ventilation problem, when compared with those of other types of industrial buildings, would be more normal.

It should not be considered that propeller fans, however large, are a panacea for all troubles. The application of this type of fan is limited, as the fan does not operate efficiently against resistance and is affected by wind currents, so that its output under certain conditions may well be ineffective.

In regard to the suggestion that the size of building is a function of the amount of heat likely to be wasted, I think that if large and spacious buildings become necessary to disperse heat, clearly far too much heat is being released to waste, and this is the problem to be tackled.

It was not suggested that small air-douching nozzles should be used for general ventilation, but that such nozzles could be used individually by the operators to relieve heat strain.

Mr. Holbeche speaks of air velocities of 200–500 ft./min., with man-cooling fans. Such draughts might well be dangerous to the health of the operators if the temperature were uncontrolled, as is presumably the case with the man-cooling fan.

South African Coke Ovens

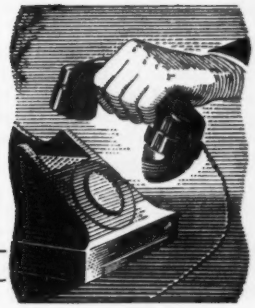
The battery of 54 W-D Becker Coke Ovens forming part of the new Vanderbijl Park Steelworks in South Africa has now been put into operation. This complete coke-making installation, which will carbonize over 1100 tons of coal per day and cost some £1,500,000, includes coal-and coke-handling equipment and comprehensive by-products recovery and treatment plants.

It is the fifth coke-oven installation to be built for the South African Iron and Steel Industrial Corporation, Limited, by the Woodall-Duckham Company of London.

Sintering Strands

Two new sintering strands have started production at the Appleby-Frodingham branch of The United Steel Companies, Ltd. Each strand has a capacity of 1000 tons of air-cooled sinter per day. After the two old strands have been reconditioned the total daily capacity of the plant will be nearly 4000 tons. The remainder of the ore preparation development programme is scheduled to be finished before the middle of 1951.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting

The Annual General Meeting of the Institute will be held at the offices of the Institute from **30th May to 1st June, 1951.** The detailed programme will be published in the May issue of the *Journal*. Apart from formal business the discussions will be devoted mainly to blast-furnace developments.

Awards

Williams Prize

The Williams Prize for 1950 has been awarded jointly to **T. H. Harris,** Manager of the Electric-Melting Shop of the Brymbo Steelworks Ltd., Wrexham, and **W. H. Everard,** Manager of the Steel Melting Plants of Messrs. Edgar Allen and Co., Ltd., Sheffield, for their paper on "*The Use of the Oxygen Lance in British Electric Furnace Practice.*" Mr. **D. J. O. Brandt,** the third co-author of the paper, is not eligible to receive the Prize.

Biographical details of the authors were given in the August, 1950, issue of the *Journal* (pp. 456–457).

Andrew Carnegie Medal

The Andrew Carnegie Silver Medal for 1950 has been awarded to **W. B. Winterbottom,** Reader in Metallography at the Technical University of Norway, for his paper on "*Optical Studies of the Oxidation of Iron at Temperatures in the Range* 20–265° C." Biographical details of Mr. Winterbottom were given in the May, 1950, issue of the *Journal* (p. 101).

NEWS OF MEMBERS

▶ Mr. J. A. Anderson has left Messrs. Steel, Peech and Tozer, Rotherham, to join the staff of William Beardmore and Co., Glasgow, in a technical advisory capacity.

▶ Professor P. G. Bastien, Scientific Director of Schneider and Co., has been elected President of the Société des Ingénieurs Soudeurs and of the 5th Section (Applied Physics) of the Société des Ingénieurs Civils de France.

▶ Mr. C. G. Conway has joined the staff of the Chief Scientists' Division, Ministry of Fuel and Power, London.

▶ Mr. D. L. Davies, formerly at the Panteg Works of Richard Thomas Baldwins, Ltd., has been appointed Production Manager of Signode Ltd., Swansea.

▶ Mr. C. Dinsdale has been appointed Regional Works Metallurgist, Eastern and North-Eastern Regions of British Railways.

▶ Mr. G. E. Dunlap has been appointed Development Metallurgist in the Commercial Research Department of the American Brake Shoe Co., New York.

▶ Mr. S. Klemantaski has been awarded the Ph.D. degree of the University of London and the Diploma of Imperial College, London.

▶ Dr. W. C. Newell, who was Head of the Steel Castings Division of B.I.S.R.A. until it was recently taken over by the British Steel Founders Association, is to take up farming in Northamptonshire. His many friends will wish him success in this new field of activity.

▶ Mr. V. Pendred has left the Skinningrove Iron Co., Ltd., and is now with Messrs. Head Wrightson and Co., Ltd., London.

▶ Mr. H. W. I. Rees, formerly Plate-Mill Manager with the Consett Iron Co., Ltd., has been appointed representative for the same Company at Birmingham.

▶ Mr. H. H. Symonds has resigned his post as Scientist-in-Charge of the Midland Laboratory Guild to become Foundry Manager at the Dudley Port Foundry of Messrs. H. B. Barnard and Sons, Ltd.

▶ Dr. Magnus Tigerschiöld is taking up a new appointment as from 1st June (*see* also p. 454: 'Jernkontoret').

Obituary

Mr. F. B. Bell of the Edgewater Steel Company, Pittsburgh, U.S.A., in May, 1949. It is regretted that this information has only now been received.

Mr. W. Fraser, Chairman and Managing Director of Lochrin Ironworks, Coatbridge, on 28th September, 1950.

Mr. R. W. Idle, Assistant Blast-Furnace Engineer at the Parkfield Works of Messrs. Ashmore, Benson, Pease and Co., Ltd., on 4th October, 1950.

Mr. L. Levy, formerly Chairman of George Cohen, Sons and Co., Ltd., on 7th November, 1950.

Mr. A. J. McFarland, of the Wheeling Steel Corporation, on 28th November, 1950.

Mr. F. Herbert, M.B.E., fomerly Director and Technical Representative of Kayser Ellison and Co., Ltd., on 5th January, 1951.

Mr. D. M. Ross, formerly General Manager of Lancashire and Corby Steel Manufacturing Co., Ltd., on 9th January, 1951.

Mr. S. G. Coade, Assistant Works Manager with Messrs. Dorman, Long and Co., Ltd., on 19th January, 1951.

Mr. K. W. Caulfield, of the Tin Research Institute, on 25th January, 1951.

CONTRIBUTORS TO THE JOURNAL

D. W. Gillings, Ph.D., B.Sc.—Head of Carbonization Research at The Central Research Establishment, National Coal Board. Dr. Gillings was born in 1916 and was educated at University College School and at University College, London. He graduated with First Class Honours in Chemistry in 1936 and obtained the Ph.D. degree two years later. From 1939–46, Dr. Gillings was employed in the Chemical Defence Department of the Ministry of Supply. He became Head of the Field

Trials Section of the British Iron and Steel Research Association in 1946 and three years later joined the Scientific Department, National Coal Board, on the staff of the Director General. He has recently been appointed to his present position as Head of Carbonization Research.

IRON AND STEEL ENGINEERS GROUP

The **Fourteenth Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Thursday, 5th April, 1951.** The following is the detailed programme :

10.30 A.M.–12.45 P.M.—Discussion on the paper "*Electric Drives for Reversing Hot Mills,*" by P. E. Peck (March, 1951, *Journal*).

12.45–2.0 P.M.—Buffet Luncheon.

2.0–4.30 P.M.—Discussion on the paper "*Hot Bloom and Slab Shears,*" by J. A. Kilby (February, 1951, *Journal*).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Steel Founding

An agreement has recently been reached between the British Iron and Steel Research Association and the Research and Development Division of the British Steel Founders' Association whereby the latter becomes responsible for the co-operative research requirements of the steel foundry industry.

Work which has been initiated by B.I.S.R.A. in the steel-castings field is to be continued under the auspices of the Research and Development Division of the B.S.F.A., certain facilities and funds having been placed at the disposal of the Division by B.I.S.R.A. so that the combined programme of work now confronting the Division can proceed without interruption.

This new and important step also provides close co-ordination on subjects of common interest between B.I.S.R.A. and the Steel Founders' Research Organization, to their mutual advantage.

It is recognized that the Steel Castings Division of B.I.S.R.A. has successfully supervised and greatly extended steel castings research since the Steel Castings Research Committee of The Iron and Steel Institute ceased to operate about five years ago, but that the time has now come for the steel foundry industry to take over and support this work in a manner best suited to its own particular needs.

With the termination of the Steel Castings Division of B.I.S.R.A. the Council of the Association has recorded its appreciation to Dr. Newell, who retired on the 28th February, of the valuable work performed by the Division under his leadership.

MEMOIRS

Robert L. Brunton, B.Eng. died on 7th April, 1950. He was educated at the University of New Zealand where he obtained the B.Eng. degree in electrical and mechanical engineering. In April, 1933 he became resident service engineer with the Acetone Illuminating and Welding Co., Ltd., New Zealand. Mr. Brunton was elected a Member of The Iron and Steel Institute in 1942 and was also a member of the Institute of Metals. In 1947 he was Chairman of the South Auckland Branch of the New Zealand Institute of Welding. He was on the Board of Managers of the Hamilton Technical High School.

Kenneth W. Caulfield, M.Sc., A.I.M., died on 25th January, 1951. He was born at Smethwick in 1922 and was educated at Holly Lodge Grammar School and at Birmingham University. After graduating in metallurgy in 1942 he joined the staff of the Tin Research Institute, Greenford. In 1945 he was awarded the M.Sc. degree for a thesis submitted to Birmingham University. He was elected an Associate of the Institution of Metallurgists in 1947. Mr. Caulfield's researches were principally concerned with tinplate technology and he had published a number of papers dealing with the application and testing of protective coatings. He was elected a Member of The Iron and Steel Institute in 1949 ; he was also a member of the Institute of Metals.

Samuel G. Coade, A.I.M., Assistant Works Manager with Messrs. Dorman Long and Co., Ltd., died on 19th January, 1951. He was born in May 1912 and educated at St. Bee's School in Cumberland. He started his technical training under The United Steel Company's apprenticeship scheme, on completion of which he was employed as blast-furnace assistant at Workington. He was appointed assistant blast-furnace manager at the Redburn Works of the Company and later blast-furnace manager at the Skinningrove Iron and Steelworks.

After serving in the Royal Air Force during World War II, when he received the D.F.C., he became blast-furnace manager at the Redcar Works of Messrs. Dorman, Long and Co., Ltd. He was later appointed Assistant Works Manager.

Mr. Coade was elected a Member of The Iron and Steel Institute in 1936. He was an Associate of the Institution of Metallurgists, and a member of the American Iron and Steel Institute and of the Cleveland Institution of Engineers.

John H. Farmer died on 8th November, 1950. He was born at Nottingham in 1885 and educated at Loretto. He started work as an apprentice engineer at Fairfield Shipbuilding and Engineering Co., Ltd., Glasgow, and later spent a period of service as a sea-going engineer and obtained his Board of Trade Certificates. In 1914 Mr. Farmer joined the Central Marine Engine Works of William Gray and Co., Ltd. He was successively appointed Outside Manager and Assistant General Manager. In 1920 he became a Director of the Company, and in 1936 he was appointed General Manager of the Central Marine Engine Works.

Mr. Farmer was a member of the Standing Committee of the North East Coast Engineering Employers' Association, serving on various Committees of the Association. He became a Member of The Iron and Steel Institute in 1941, and was also a member of the Institute of Metals and of the North East Coast Institution of Engineers and Shipbuilders.

Sir Edward George, formerly Managing Director of the Consett Iron Co., died on 25th October, 1950. Born at Oswestry, Sir Edward was Secretary of a Lancashire colliery company before joining the Consett Iron Co. in 1905. In 1919 he was appointed General Manager and ten years later became a Director. He was made Deputy Chairman of the company in 1935 and Managing Director shortly afterwards. Sir Edward was also Chairman of the Orconera Iron Ore Co., an ex-Director of the Consett Spanish Ore Co., an Honorary Vice-President of The Iron and Steel Institute, of which he was a Founder Member, and Chairman of the British Sulphate of Ammonia Association.

Sir Edward was President of the National Federation of Iron and Steel Manufacturers in 1933. He was knighted in 1939 for his services to the industry.

Lt.-Col. Sir John Greenly, K.C.M.G., C.B.E., M.A., an Honorary Vice-President of the Institute, died on 31st December, 1950. He was born in 1885 and educated at Charterhouse and Trinity College, Oxford University. He was trained as a civil engineer in the firm of Sir John Wolfe Barry and Partners. Commissioned in the Hertfordshire Regiment in 1906, he served in the First World War and was twice mentioned in despatches. He

attained the rank of lieutenant-colonel in 1917. During the latter part of the war he was appointed Assistant Controller of Inspection of Munitions of War at the Ministry of Munitions, and received the C.B.E. in 1919.

In 1920 Sir John became Joint Managing Director of Messrs. William Foster, Pascoe, Grenfell and Co., copper manufacturers and smelters, and subsequently Joint Managing Director of British Copper Manufacturers, Ltd. In 1929 he became a Director of Messrs. Babcock and Wilcox, Ltd., and served as Chairman of the Executive Committee ; he was appointed Deputy-Chairman of the Company in 1932, and became Chairman in 1937. In the same year he became Chairman of the British Non-Ferrous Metals Research Association, and was a Member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research from 1937 to 1943.

During 1938–39 he also served on the Industrial Panel to the Air Ministry and as Chairman of the Prime Minister's Advisory Panel of Industrialists on Rearmament. From 1939 to 1940 he acted as Controller-General of the British Supply Board in Canada and U.S.A., and in 1941 he became Deputy Chairman and Administrator of the National Fire Prevention Executive. For public services, both in this country and abroad, Sir John was created a K.C.M.G.

Apart from his numerous directorships, Sir John was a Past-President and Fellow of the Institute of Metals ; Past-President and Fellow of the Institute of Fuel ; Member of Council of the British Welding Research Association ; Member of Council (Past-President) of the Institute of Engineering Inspection ; Member of Council (Past-President) of the Combustion Appliance Makers' Association ; Chairman of the Coal-Burning Appliances Joint Consultative Board ; Vice-President of the Coal Utilization Joint Council ; Member of Council of the British Coal Utilization Research Association ; Member of the Fuel Research Board ; Member of the Fuel and Power Advisory Council. He was elected an Honorary Vice-President of The Iron and Steel Institute in 1944. He was also a member of the Institution of Mechanical Engineers.

Robert William Idle died on 4th October, 1950. He was born at Stockton-on-Tees in 1900 and received his early education at Holy Trinity School, Stockton, and later attended continuation classes at Stockton Technical College. From 1915–21 he was apprenticed to Messrs. Head, Wrightson and Co., Ltd. On leaving this Company he joined the construction department of the Furness Shipbuilding and Engineering Co., as detailing draughtsman on bridgework tanks, building, etc. and was later employed in the design and estimating department. Mr. Idle spent the following two years with the Cleveland Bridge Co., Darlington, as a designer-draughtsman, before taking up a position as structural designer with Ashmore, Benson, Pease and Co., Ltd. where, until 1950, he was responsible for most of the structural work connected with all blast-furnace plant built by the Company. Prior to his death he was officiating deputy leader of the blast-furnace section of the Company. Mr. Idle was elected a Member of The Iron and Steel Institute in 1947.

Lawrence Levy, Chairman of George Cohen Sons and Co., Ltd., died on 7th November, 1950. He was born in London in 1876 and educated at the City of London School. He joined the firm of George Cohen and Sons as an apprentice and later became a junior partner and took a particular interest in the scrap iron and steel side of the firm's trading. He took a leading part in the management of the associated Shipbreaking Company.

In 1924, when George Cohen Sons and Co. was registered as a limited company, Mr. Levy became a Director. He was Chairman of the Company from 1928–1947. He was also Chairman and Managing Director of a subsidiary company, the New London Electron Works, Ltd., and Chairman of Batchelor, Robinson and Co., Ltd. He was elected a Member of The Iron and Steel Institute in 1928.

Major S. Guy Newton, Joint Managing Director of Brown Bayley's Steel Works, Ltd., died on 22nd December, 1950. He was born in 1889 and educated at Worcester College. He started work at Brown, Bayley's Steel Works, Ltd., as representative in the Yorkshire area, in 1919. He was appointed Commercial Manager in 1931, Director in 1932, and Joint Managing Director in 1948.

Major Newton had been Chairman of the Alloy Steels Association since 1944, and was a member of the executive of the British Iron and Steel Federation, and a member of the Production and Supplies Committee. He was also Chairman of the Hoffman Manufacturing Co., Ltd., and of the Taylor Rustless Fittings Co., Ltd. He was a member of the British Steel Producers' Conference, the Alloy and Stainless Steel Conference, the Crucible and High Speed Steel Conference, and the Light Rolled Steel Products Conference.

Major Newton was elected a Member of The Iron and Steel Institute in 1938.

Fred M. Osborn died on 8th November, 1950. He was born on 16th April, 1874, and educated at Leys School, Cambridge. He joined Samuel Osborn and Co., Ltd., in 1892, and became a partner in 1898. He was appointed Chairman of the Board of Directors in 1948.

He had many activities in connection with youth, the unemployed, and with hospitals. During the First World War he was a member of the Sheffield Munitions Committee and Chairman of the Sheffield Interviewing Board of Appointments.

Mr. Osborn became a Member of The Iron and Steel Institute in 1950 and was a Member of the Senate of Sheffield University.

David Ross died on 9th January, 1951. Born in Coatbridge, he served his apprenticeship as a draughtsman with Lamberton and Co., Ltd., from 1903 to 1908. He joined Messrs. Lysaghts, Ltd., at Newport, and later worked on rolling-mill design at Messrs. Fraser and Chalmers. In 1936 he took up an appointment at Brasserts London office (now John Miles and Partners, Ltd.) working on the cold-mill installation for the Lancashire and Corby Steel Manufacturing Co., Ltd., and on the stainless steel mill for Darwins, Ltd. He became General Manager of the (then) new Lancashire and Corby plant in 1938 and held this position until his retirement in 1949. Mr. Ross had recently gone to Australia to take up an appointment in connection with the Lysaght development scheme for strip mills. He was elected a Member of The Iron and Steel Institute in 1931.

E. Arthur Williams, Chairman and Managing Director of the Clayton Tin Plate Co., Ltd., died on 16th November, 1950. He was educated at Mill Hill and at Sheffield University. He was one of the leading figures in the tinplate industry in West Wales and his knowledge of the practical aspects of the tinplate industry was almost unequalled. Mr. Williams had been a member of the Joint Standing Committtee of the Joint Industrial Council for many years. He also served on the Executive and Emergency Committees of the Welsh Plate and Steel Manufacturers' Association. He made many industrial visits to the U.S.A. and Canada, and went on a Government-sponsored inspection of millplant in Germany immediately after the last war. During the last few years Mr. Williams had been Vice-Chairman of the tinplate Joint Industrial Council.

He was a Director of the colliery firm of Glasbrook

Bros., Ltd., and a Member of a committee of the British Iron and Steel Federation. He was a Member of Council of University College, Swansea.

Mr. Williams was elected a Member of The Iron and Steel Institute in 1939.

Keith W. Winsor, General Production Manager of the Electric Section of The Commonwealth Industrial Gases, Ltd., died on 18th June, 1950. Mr. Winsor was born in 1912 and was educated at Melbourne University where he took a three-year engineering course as a senior government scholarship winner. In 1935 he started work as a draughtsman with the E.M.F. Electric Company Pty., Ltd., and he was subsequently in charge of the research laboratories. Later he became Electrode Production Manager. During World War II he obtained a commission in the A.I.F. but on representations from his firm he was released and returned to the E.M.F. Company's service. In 1945 Mr. Winsor spent six months in the United States and early in 1946 he was transferred to The Commonwealth Industrial Gases, Ltd., of which the E.M.F. Company is a subsidiary, and became General Production Manager of the Electric Section of C.I.G. At the same time, he was appointed a Director of E.M.F. and other subsidiaries. At the time of his death, Mr. Winsor was on a business visit to England on behalf of his Company.

He was elected a Member of The Iron and Steel Institute in 1943 and was a member of a number of metallurgical societies in Australia and the U.S.A.

NEWS OF SCIENCE AND INDUSTRY

Recent Advances in Theoretical Metallurgy

An advanced course of about nine lectures, each of which will be followed by a discussion, will be given in the Department of Chemistry and Dyeing at Bradford Technical College, on Thursdays at 7 p.m., commencing on 10th May, 1951. The lectures will be given by Mr. E. W. Fell, Senior Assistant in Metallurgy in the College, Mr. W. Moore, Senior Assistant in Physical Chemistry, and Mr. R. B. Bentley, Assistant Lecturer in Physical Chemistry.

The course is designed particularly for practising metallurgists and advanced students, and will provide an opportunity to keep abreast with modern developments and their practical application. Forms of application, which should be completed and returned as soon as possible, may be obtained from the Principal, The Technical College, Bradford.

National Coal Board Scholarships, 1951

In 1951 the National Coal Board will again offer up to 100 University Scholarships to give boys and young men the best education and practical experience that can be offered to fit them for a career in the Mining Industry, leading in due course to posts of high technical responsibility.

Awards will usually be made for university courses in Mining Engineering. A small number may be given in Fuel Technology; and a limited number may be given in Mechanical or Electrical Engineering, but these will be available only to persons employed in the coal industry. A few awards may be given to graduates in science, mechanical engineering, or electrical engineering to enable them to qualify as mining engineers; exceptionally such 'conversion' awards may be given in the opposite direction.

All scholarships will cover university fees and maintenance allowances. Application forms and a brochure containing further particulars may be obtained from the Education Branch, National Coal Board, Hobart House, Grosvenor Place, London, S.W.1. Application forms must be completed and returned not later than 14th April, 1951.

Jernkontoret

The Director of Research of Jernkontoret, Dr. Magnus Tigerschiöld, is leaving to take up an important position as expert on metallurgical questions to the Grängesberg–Luossavaara–Kiirunavaara Company, with effect from 1st June, 1951.

Dr. Tigerschiöld, who has been Director of Research of Jernkontoret since 1936, was awarded the Bessemer Medal, in 1947, in recognition of his distinguished services to the Swedish iron and steel industries.

Changes of Address

THE RESEARCH LABORATORIES of the ARC MANUFACTURING CO., LTD. have removed from Craven Park Road, Harlesden, London, N.W.2, to Nitshill, Glasgow, S.W.3. The Head Office of the Company is still at Goldhawk Road, London, W.12 and has not removed to Glasgow as announced in the January issue of the *Journal*.

BRITISH STEEL FOUNDERS' ASSOCIATION, Research and Development Division, has removed to Broomgrove Lodge, Broomgrove Road, Sheffield, 10.

DIARY

5th Apr.—IRON AND STEEL ENGINEERS GROUP—Fourteenth Meeting—4 Grosvenor Gardens, London, S.W.1, 10.30 A.M.

5th Apr.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*A Review of the Cold Reduction and Finishing Processes*," by H. Edwards—Station Hotel, Dudley, 7.30 P.M.

5th Apr.—LIVERPOOL METALLURGICAL SOCIETY—Annual General Meeting and Presentation of Prize-Winning Student Papers—Electricity Service Centre, Whitechapel, Liverpool, 7.0 P.M.

5th Apr.—ROYAL INSTITUTE OF CHEMISTRY (London and S.E. Counties Branch)—"*Recent Trends in Fuel Research*," by A. C. Monkhouse—King's Fare Restaurant, King Street, Luton, 7.30 P.M.

11th Apr.—INSTITUTE OF WELDING (West of Scotland Branch)—Annual General Meeting and Discussion on High Current Welding including Automatic Welding—39 Elmbank Crescent, Glasgow, 7.0 P.M.

13th Apr.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Annual General Meeting and Paper on "*Operation of the Blast-Furnace Under High Top Pressure*," by R. P. Towndrow—39 Elmbank Crescent, Glasgow, 6.45 P.M.

13th Apr.—SHEFFIELD METALLURGICAL ASSOCIATION (Modern Methods of Analysis Group)—"*The Determination of Chromium, Copper and Molybdenum in Residual Amounts*," presented by J. Harrison, L. Gardner, C. L. Grayson, and J. A. Oldfield—Mining Lecture Theatre, St. George's Square, Sheffield, 7.0 P.M.

17th Apr.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Metallurgical Research at the N.P.L.*, by N. P. Allen—Grand Hotel, Sheffield, 7.0 P.M.

25th Apr.—FARADAY SOCIETY—Informal Discussion on 'Flotation'—Department of Mineralogy and Petrology, University of Cambridge, 11.0 A.M.

TRANSLATION SERVICE

(The previous announcement was made in the March, 1951, issue of the *Journal*, p. 326).

TRANSLATION AVAILABLE

No. 419 (Czech.) A. BICHLER: "Problems Associated with the Life of Chilled Rolls." (*Hutnické Listy*, 1950, vol. 5, No. 3, pp. 89–93).

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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WELDING AND FLAME-CUTTING

The Measurement of the Secondary Current in the Testing of Spot-Welding Machines. L. V. Glebov. (Avtogennoe Delo, 1948, No. 12, pp. 23–24). [In Russian]. A method based on the use of a differential transformer is described; it simplifies the determination of the secondary current in a spot-welding machine. In tests with secondary currents of 102–250 amp. the errors in the values obtained were less than — 2.—S. R.

On the Nature of the Primary Crystallization of the Weld Metal Pool. A. M. Makara and B. I. Medovar. (Avtogennoe Delo, 1948, No. 12, pp. 25–27). [In Russian]. Some results of previous experiments on the crystallization of the fused metal in a weld, which showed that wave formation in the liquid could not explain the crystallization taking place in well-defined layers, are re-examined. Further experiments with a submerged arc, in which this form of crystallization was obtained, although wave formation was excluded, are described. Photomicrographs of the crystalline structure are given, and it is shown that aluminium greatly increases the stratification. Tamman's theory of crystallization is shown to be inapplicable to the conditions existing in the fused metal during welding, the crystallization being governed by the constancy of the product of the thickness of the crystallized layer and the speed of crystallization in the direction of the temperature gradient.—S. K.

Contact Electric Brazing of Band Saws at the Kirov Works. Z. M. Ryzhik. (Avtogennoe Delo, 1948, No. 10, p. 28). [In Russian]. Band saws 0·5 to 5·0 mm. thick and up to 60 mm. wide have been successfully brazed with bronze foil and a borax flux in an electric brazing machine, the time required per joint being 1·3–1·5 min.—S. K.

Manufacture of Flame-Cutting Torches at the Kolomensk Locomotive Works. P. I. Shorin. (Avtogennoe Delo, 1948, No. 10, p. 29). [In Russian]. A brief description is given of oxy-acetylene cutting torches, developed during the war at the Kolomensk Works, for cutting metal 50 to 400 mm. thick. The approximate consumptions of oxygen and acetylene are 8–52 and 0·6–1·6 cu. m./hr. respectively.—S. K.

The Testing of Acetylene Seals. G. N. Dmitriev. (Avtogennoe Delo, 1948, No. 12, pp. 10–12). [In Russian]. Procedures for determining the resistance to gas flow, the maximum permissible gas flow, and the resistance to oxy-acetylene blow-back of low, medium, and high-pressure hydraulic seals on acetylene generators are described.—S. K.

Heating by Special Torches in the Trimming of Welded Structures. A. Ya. Brodskii. (Avtogennoe Delo, 1948, No. 2, pp. 20–22). [In Russian]. Requirements and performances of torches for trimming welded joints by local heating to 800–850° C. are discussed and a 17-jet oxy-acetylene torch is described. The heating of a thin-walled tube by this type of torch is considered in detail, and, making a number of simplified assumptions, an equation is deduced for the calculation of thermal conditions throughout the tube. Using this equation and data taken from the literature, theoretical curves of temperature against time are plotted and shown to agree well with experimental measurements for the first 45 sec. of the heating process.—S. K.

Universal Templates for Mechanical Flame-Cutting. Z. B. Dreizenshtok. (Avtogennoe Delo, 1948, No. 2, p. 23). [In Russian]. In the device described, the contour of the shape to be cut is painted on a sheet of plywood; iron strips 7 × 7 or 8 × 8 mm. are then nailed along the pattern produced to act as guides for an electromagnetic tracing device. The limited experience available has shown these templates to be satisfactory.—S. K.

Oxygen-Flux Cutting of High-Chromium Steel. S. G. Guzov. (Avtogennoe Delo, 1948, No. 12, pp. 24–25). [In Russian]. A very brief account is given of the method of cutting high-chromium steel with injection of finely divided iron-rich flux into the gas stream for the removal of the refractory chromium oxide produced by the oxidation of the steel.—S. K.

Flame Cutting. J. T. Lewis, jun. (Welding Journal, 1950, vol. 29, Feb., pp. 116–120). Flame-cutting installations and procedures are described. As many as eight simultaneous cuts can be made and strips of any width can be cut from all thicknesses of plates and in lengths up to 30 ft. Uniform cutting speeds are obtained by using a motor drive and each torch can be raised and lowered independently. Costs and labour charges are discussed.—U. E.

Use of Propane instead of Acetylene for Cutting and Welding. K.-F. Mewes. (Stahl und Eisen, 1950, vol. 70, Apr. 27, pp. 381–382). Because of the breadth of the flame, propane–oxygen mixtures are unsuitable for welding. For cutting thick plates, propane requires more oxygen than acetylene and, on account of the lower flame temperature, it is slower in action. Propane–oxygen is suitable for cutting thin plates and light metals.—J. P.

Official Examination Syllabus for Welders. S. Synek. (Svařování, 1950, vol. 10, June, pp. 74–84; Aug., pp. 106–112). [In Czech]. A draft specification of examinations for welders of structures, boilers, and pipelines is given. It covers both theory and practice.—E. G.

MACHINING AND MACHINABILITY

Superior Machining at Lower Cost with MX. G. R. Caskey. (Iron Age, 1950, vol. 165, May 18, pp. 95–98). MX is a Bessemer steel (C 0·08% max., Mn 0·70–1·00%, P 0·07–0·12%, S 0·24–0·33%, Si 0·01% max.) produced by the Carnegie-Illinois Steel Corp. Mechanical properties are similar to B-1113 steel, but the reduced carbon and silicon impart considerably greater machinability, giving savings of 16–22% on production runs.—A. M. F.

Rapid Testing Methods for Machinability Investigations on Free-Machining Steels. W. Ulbricht. (Die Technik, 1950, vol. 5, Feb., pp. 64–68). Methods of arriving at machinability ratings of free-machining steels, based on composition, strength, cutting force, and examination of chips are described and discussed.—R. A. R.

Machinability of Free-Cutting Steels Measured by New Yardstick. (Steel, 1950, vol. 126, Jan. 16, pp. 80, 82, 84). A method of measuring machinability of free-cutting steels has been developed at the Battelle Memorial Institute. The test is based on the finding that when a horizontal pressure of fixed value is applied to the feed mechanism of a lathe and consequently to the cutting tool, steels of different machining quality cut at different rates. Machinability ratings based upon the close relation of these feed variations were secured on different steels under controlled laboratory conditions. The standard test norm is taken as a spindle speed of 377 r.p.m. at 81 lb. tool pressure and 0·003 in. of feed per revolution.—A. M. F.

Influence of Lead Additions on the Mechanical Properties and Machinability of Some Alloy Steels. J. Woolman and A. Jacques. (Journal of The Iron and Steel Institute, 1950, vol. 165, July, pp. 257–267). The mechanical properties, including fatigue resistance, of a series of normal and lead-bearing carbon and alloy steels produced from the same melt, in various conditions of heat-treatment, are determined in both longitudinal and transverse directions. The effect of lead additions on machining properties is measured in turning, sawing, and drilling tests. The effect of additions of different-sized lead shot is examined.

Machining Stainless Steel Parts. (Machinery, 1950, vol. 76, Apr. 13, pp. 519–524). The methods used at the works of the De Havilland Engine Co. Ltd. for machining stainless steel components for jet propulsion units are described.

R. F. F.

Notes on Machining Stainless Steel. R. H. King. (Aircraft Engineering, 1950, vol. 22, Feb., pp. 55–56). Recommendations are made on techniques for machining straight chromium and chromium–nickel stainless steels.—R. A. R.

Cutting Temperature, Criteria of Machinability. O. Peters. (Revue Générale de Mécanique, 1950, vol. 34, Apr., pp. 120–126; May, pp. 173–178). The author describes tests carried out on two steels (a carbon steel and a nickel–chromium steel), to study the cutting temperature as a criterion of machinability. The temperature measurement is carried out using two cutting tools with different thermo-electric properties (one high-speed steel, the other with a tungsten carbide insert) connected by a millivoltmeter and cutting simultaneously on the same specimen. Factors affecting the cutting temperature include: Feed and depth of cut, cutting speed, and mechanical properties of the steels. A formula for the machinability is presented.—R. F. F.

The Properties of the Hard Metals and Their Influence on the Production and Use of Tools. J. Hinnüber. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Feb. 11, pp. 111–117). The author divides the sintered carbides into two groups: those which contain titanium carbide, and those which do not. The difference in life between regrinds of the groups depends on the properties of the material on which they are used. In general, the presence of titanium carbide improves the life when machining steel. The methods of fixing hard-metal tips to lathe tool shanks and boring bits are described and the optimum cutting angle is discussed. Data on the oxidation and corrosion resistance and the mechanical properties are given. Finally, some new applications are described.—R. A. R.

Hot Machining. G. Hubbard. (Steel, 1950, vol. 126, Feb. 27, pp. 60–62). This paper is a short survey of recent experimental work on the machining of metal in the hot state. The author stresses the increased speed of production and reduction in power requirements that are features of this system.—A. M. F.

Giant Gear Cut While Still on Drive. E. C. Denne. (Iron and Steel Engineer, 1950, vol. 27, Jan., p. 134). The reconditioning of the contacting surfaces of a 190-ton gear in the 96-in. plate mill of the Carnegie-Illinois Steel Corp. is described. The gear was reconditioned in place with specially designed cutting equipment. The job was completed in only 14 days.—M. D. J. B.

Hobbing Cavities in Alloy Steels. J. Sekowski. (Steel, 1949, vol. 125, Oct. 31, pp. 62–63). 'Hobbing' in this connection signifies the forming of dies for plastic moulds, etc., by pressing a master 'hob' into a steel blank. The steel most commonly used for the hob today is a chromium–silicon–manganese steel with 2·5% of tungsten; high-speed steels may be used when greater pressure is applied in the forming process. The steel most used for the mould material contains carbon 0·08%, chromium 1·4%, nickel 0·5%, and molybdenum 0·25%; an air-hardening steel containing carbon 0·10%, chromium 5·0%, silicon 0·20%, molybdenum 0·90%, manganese 0·30%, and vanadium 0·35% may also be used. The latter will require more annealing before the cavity is fully formed. Whatever steels are employed, care must be taken in the design of the hob to avoid undercuts and unbalanced sections.—J. P. S.

CLEANING AND PICKLING

Chemico's New Pickle Liquor Process. F. J. Bartholomew. (American Society of Mechanical Engineers: Chemical Engineering, 1950, vol. 57, Aug., pp. 118–120). A semi-commercial plant has been set up to recover sulphuric acid from pickle liquor. Submerged combustion is used in the evaporation of the liquor to 60–70% acid concentration, which then contains only 1% of ferrous sulphate. The $FeSO_4$, which is precipitated, is mixed with iron oxide fines and 12% coal, and sintered. The SO_2 from this process is used in the contact sulphuric acid plant. Flow diagrams of both stages are given.—T. E. D.

Soft Grits Provide Low Cost Method for Blast Cleaning Metals. T. F. Clark and E. C. Lathrop. (Materials and Methods, 1950, vol. 31, May, pp. 67–69). The authors describe how grits from agricultural residues, such as corncobs, rice, and nut shells can be used in conventional blasting equipment for degreasing, removing welding scale, and cleaning metal surfaces prior to plating. The relative efficiencies of different types of grit have been determined by blasting steel panels coated with six layers of baked-on resin-base paint. The times to penetrate the paint, the changes in particle size, and the amounts of dust formed are tabulated.—P. M. O.

Mechanical Scaling of Low Carbon Steel Rods. J. Peignier. (Wire Industry, 1950, vol. 17, Sept., pp. 749–751: Wire and Wire Products, 1950, vol. 25, Aug., pp. 649–650, 693, 694). The article has been contributed by the Société Métallurgique de Gorcy of Paris. The mechanical removal of scale, which replaces acid cleaning and permits the direct feeding of rods into the wire-drawing machine, is developing rapidly in France. Advantage is taken of the brittleness and poor adhesion of the oxide layer on the hot-rolled steel by bending the rod over two pulleys in the vertical and horizontal planes; this causes the bulk of the scale to flake off. The remainder is scraped off by hard disc-shaped brushes rotating in opposite directions, whilst the whole brush assembly revolves round the rod axis. The descaling unit, manufactured by Etablissements Lyne of Albert (Somme), is 50 in. long, 24 in. wide, and 42 in. high, and is used for 0·197-in. dia. rods. It is totally enclosed and all parts are protected against scale dust. Both pulleys and brushes are turned by the drag of the moving rod so that no auxiliary drive is needed. Mechanical and conventional chemical scale-removing processes have been compared by tests. Both processes remove approximately 99% of the scale. The mechanically descaled rods are rougher, affording a better 'key' for the soap. Mechanical scaling causes the wire surface to harden slightly, but the resulting increase in tensile strength and lower ductility disappears completely after the fourth draft, when the properties are the same as those of the wire drawn from the pickled rod.

J. G. W.

Electrolytic Degreasing. (Galvano, 1949, vol. 18, July, pp. 8–11). Some precautions to be observed in degreasing metals before nickel plating are described. Advantages are claimed for a combined degreasing and copper-plating bath.

J. P.

Applications of the Oxy-Acetylene Flame. F. H. Dill. (International Acetylene Association: Australasian Engineer, 1950, Jan. 7, pp. 53–55). The author describes in general terms how the oxy-acetylene torch is being used extensively for straightening, forming, and cleaning structural steel. Most steel used for structural work is not harmed by the excessive thermal shock, although severely cold-worked steel should not be heated to temperatures of 400° to 700° F. because brittle fracture may result. The ability to heat local areas rapidly for hammer or mechanical bending, without resorting to furnaces is in many jobs very desirable. The flattening of buckled plates, the correction of distortion and the cambering of heavy section beams can all be accomplished rapidly and easily by heat shrinkage. Flame-cleaning before painting is more successful, easier, and costs only half as

much as sand-blasting. Some of the above processes require so much acetylene that they are not feasible where it must be taken from cylinders.—P. M. C.

PROTECTIVE COATINGS

Electrochemical Methods in Process Control. J. Jackson. (Instrument Practice, 1950, vol. 4, Oct., pp. 653–657). The application of conductivity measurement for the purposes of laboratory and plant control is discussed. The use of D.C., with and without polarization, and A.C. bridge methods is described, together with details of measuring elements and recorders. Actual processes of electrolyte addition, electrolyte removal, and adding acids or alkalis are classified; industrial examples are given in which conductivity is an established means of control.—H. D. W.

Metal Powder Parts Successfully Plated by New Process J. F. Kuzmick. (Materials and Methods, 1950, vol. 31, June, pp. 54–56). The inherent porosity of metal-powder parts means that during any plating process, liquid and salts from the plating bath are entrapped in the interior of the parts. Thus internal corrosion occurs, and the surface plating erupts into spots. Repeated washings in hot circulating water did not cure this trouble. A new method called Etolizing has recently been developed at the Ekstrand and Tholand Powder Metallurgy Laboratory (U.S.A.), and used with good success. The method involves heat-treatment of plated parts to volatilize the residual salts out of the porous compact and through the plated coating. The plating and heat-treatment may be carried out before or after the compact is fully sintered. This heat-treatment, which is carried out at about 1500° F., also helps to bond the coating to the metal-powder compact. The process has been successfully applied to porous iron, brass and bronze compacts coated with copper, nickel, silver, chromium, copper–nickel, and copper–tin.

P. M. C.

Control of Electroplating Solutions by Analysis and Observation. K. E. Langford. (Electroplating, 1949, vol. 2, Aug., pp. 519–523; vol. 3, Dec., pp. 121–122; 1950, vol. 4, Jan., pp. 166–168; Aug., pp. 443–445, 454). Continuation of a series of articles (*see* Journ. I. and S.I., 1949, vol. 163, Dec., p. 468). Part IX continues the discussion on control of nickel-plating solutions and deals with constituents peculiar to bright nickel solutions of the cobalt-formate type. Part X deals with control of silver-plating solutions, and Part XI with chromium-plating solutions. Finally, Part XII describes the electro-analysis of plating solutions using home-made apparatus.

R. A. R.

The Simultaneous Determination of Optical Constants and the Thickness of Very Thin Metallic Layers. F. Abelès. (Comptes Rendus, 1950, vol. 231, Nov. 6, pp. 958–960). From a study of the expressions for reflection and transmission factors, the optical constants and the thickness of a layer assumed to be homogeneous and isotropic can be deduced. Cases of normal incidence of polarization both in the incident plane and at right angles to it and of Brewsterian incidence are considered.—A. G.

Fitting Hard Chromium Plating to the Job. G. C. Close. (Steel Processing, 1950, vol. 36, June, pp. 281–284). The industrial uses of hard chromium plating are: (1) Hard-surfacing, drawing, stamping, forming, and coining dies; (2) reclaiming worn machine parts; (3) protection against corrosive effects of petroleum hydrocarbon combustion; and (4) improvement and maintenance of all types of metal-cutting tools. The properties which make chromium so suitable for these several applications are extreme hardness and wear resistance, abrasion resistance, low coefficient of friction, non-seizure properties, oxidation resistance, and corrosion resistance. In order to counteract hydrogen embrittlement, all plated parts should be heat-treated at 350° F. for from 1 to 3 hr. Coating thicknesses may vary from 0·00005 in. on cutting tools to 0·030 in. on worn machine parts. Many typical applications are listed.—P. M. C.

Mechanical Giant Plates Chrome on Stainless. H. E. Head. (Iron Age, 1950, vol. 165, June 29, pp. 65–68). Briggs Manufacturing Co., Detroit, have a new installation capable of plating 3000 complex assemblies. The assembly size (5 ft. by 2 ft.) has involved the construction of a plating bath reputedly the largest in the world. Features of the process include polishing before forming.—A. M. F.

Hard-Chromium Coatings for Machinery. E. Gillet. (Machines et Métaux, 1947, vol. 31, Jan., pp. 25–28; Feb., pp. 61–62, 64; June, pp. 210–214). The advantages and disadvantages of hard chromium coatings are discussed and the preparation of the metal before coating and the determination of coating thickness are described.—R. A. R.

Nickel and Chromium Plating Compared. J. L. Bleiweis. (Metal Progress, 1950, vol. 57, Feb., pp. 200–202). It is shown that nickel can be more economical for building up worn or undersize parts, and details are given for successful nickel plating. In a list of nine points, the merits of chromium and of nickel plating are compared; chromium is harder, whilst nickel has a higher plating rate.—E. T. L.

The Determination of Impurities in Nickel Plating Solutions. L. Silverman. (Metal Finishing, 1950, vol. 48, May, pp. 59–63, 66; July, pp. 50–55). Precise step-by-step instructions are given for carrying out the estimation of cation impurities in bright nickel-plating solutions. The methods recommended are: For aluminium, colorimetric with aluminon; for ammonium, alkaline distillation and titration; for cadmium, dipyridyl colorimetric, dithizone colorimetric; for chromium, diphenylcarbazide colorimetric; for cobalt, thiocyanate colorimetric, ferricyanide potentiometric titration; for copper, thio-oxamide colorimetric, diethyldithiocarbamate colorimetric; for iron, cupferron-orthophenanthroline colorimetric; for lead, dithizone colorimetric; for magnesium, titan yellow colorimetric; for silica, perchloric acid dehydration gravimetric; for tin, molybdenum blue colorimetric; and for zinc, dithizone colorimetric.—J. P.

Weirton Starts New Electrolytic Tinning Line. (Iron and Steel Engineer, 1950, vol. 27, May, pp. 99–101). A description is given of the new electrolytic tinplating line at the Weirton Steel Co,. said to be the largest and fastest line of its type in the industry. The production capacity of the new line, which coats steel strip at speeds from 2000 to 2500 ft./min. gives the West Virginia plant an annual capacity of about 800,000 tons. Details are given of the pickling plant and plater, the electrolyte, and the chemical treatment.

The History of Vitreous Enamelling. W. E. Benton. (British Industrial Finishing, 1950, vol. 2, Apr., pp. 670–675; May, pp. 724–734). The first part describes the early history of the development of vitreous enamelling, whilst in the second part the more recent and quite modern developments are discussed as well as the control of thermal expansion of enamels and cleaning the metal before enamelling. The importance of uniform thickness in metal pressings which are to be enamelled is stressed, and opacity, wear resistance, smoothness, gloss, and colour are dealt with.—R. A. R.

Some Observations on Reactions of Enamel and Iron. G. E. Miller and B. J. Sweo. (Journal of the American Ceramic Society, 1950, vol. 33, Mar. 1, pp. 107–109). When mixtures of powdered iron and finely divided enamel frits are heated gas evolution is observed, the amount of the gas evolved being ascertained from the change in density of the fused mixtures. The amount of gas entrapped, mainly hydrogen, increased with increased time of heating to a constant level determined by the temperature; increased clay content also increased the amount of gas entrapped whereas calcined clay showed no increase. The amount of the gas entrapped is also governed by the frit, and if water is removed from the frit less gas is entrapped.—R. F. F.

A New Enamelling Furnace with Vertical Charging for Stoving Suspended Objects. W. Kuttler. (Metalloberfläche, 1950, vol. 4, Feb., pp. A18–A21). The furnace is a rectangular chamber 1200 × 800 × 3200 mm. high, the upper 2000 mm. being heated by resistance elements in the walls, the lower 1200 mm. forming a preheating chamber. It is heavily insulated and is closed by a horizontal door on rails at the bottom which is about 2 m. above floor level. Three heat-resisting metal rods pass through holes in the top end into an insulated chamber above the furnace; these are suspended from separate motor-driven hoists and carry frames on their lower ends on which the charge is suspended. For charging and unloading, the door is opened and the rod with its suspended frame is lowered to floor level. A high efficiency is claimed. For double-walled cooking appliances of 1·5-mm. sheet metal, a throughput of 400 kg./hr. is maintained with a consumption of only 225 kWh./1000 kg.—R. A. R.

Is it Possible to Calculate the Life of Anti-Corrosive Paints by the Examination of Thin Layers? J. F. Bogtstra. (Métaux et Corrosion, 1949, vol. 24, June, pp. 157–162). The investigations of the Dutch Committee on Corrosion Studies showed

that the thickness of protective coatings is very important. A study was made of curves showing the relation between the protective power and the thickness of the layer. Tests were made with different basic coatings from 35 to 50 microns thick. A relationship was shown between rust penetration through the paint and the life in days per micron of thickness. R. S.

Painting of Steel Mill Buildings and Equipment. W. W. Scherer. (Iron and Steel Engineer, 1950, vol. 27, Mar., pp. 60–63). The importance of preparing surfaces before painting, of applying coats under proper conditions, of providing an adequate thickness of paint, and of selecting the correct type of paint is discussed. The properties of primers and paints are examined in relation to service and maintenance requirements. The relative merits of oil paints, varnishes, enamels, pitch paints, lacquers, and water paints are considered. The author also discusses the influence of colours on the worker's performance and attitude. The importance of creating pleasant surroundings by planned colour schemes can no longer be neglected. The author indicates the general rules for relieving eyestrain and improving concentration in order to contribute to the general works efficiency and to produce the best psychological effects on the workers.—M. D. J. B.

POWDER METALLURGY

Sintered Carbides. A. E. Hirschfeld. (Congrés International des Fabrications Mécaniques, Sept. 13–18, 1948: Jernindustri, 1949, vol. 30, Oct., pp. 153–160; Nov., pp. 180–186). An account is given of the manufacture, properties, and machining applications of sintered carbide cutting tools. R. A. R.

Note on Surface Diffusion in Sintering of Metallic Particles. N. Cabrera. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 667–668: Journal of Metals, 1950, Apr.). A theoretical study of the rate at which the crack between a metallic plane and a spherical particle of the same material is filled up when heated at temperatures near the melting point, is presented. In a similar investigation Kuczynski showed experimentally and theoretically that, if the mechanism of transport of matter is volume diffusion of vacant lattice sites, the radius of contact x between plane and sphere is related to time t by the equation $x^5 = A.t$, A being a constant. Kuczynski also considered that, if the important mechanism is surface diffusion, the equation would be of the form $x^7 = A.t$. The present study shows this latter concept to be incorrect and the equation $x^5 = A.t$ is obeyed but with a different constant A in the case of surface diffusion. The calculations, however, are not valid for small particles.—G. F.

Seminar on the Kinetics of Sintering. A. J. Shaler. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1949, vol. 185, pp. 796–804: Journal of Metals, 1949, vol. 1, Nov.). A quantitative evaluation of some of the mechanisms in operation during the sintering of metallic powders is presented. Among these are the force of attraction between metallic particles, plastic flow, and the viscous flow taking place under the action of surface tension and gas pressure. Consideration is given to the transport of metal by recrystallization, flow, surface diffusion, and evaporation. Copper and other metals are shown to have a surface tension in the solid state comparable to that in the liquid state; this by itself is capable of causing density changes in powder compacts. Methods of calculation are outlined enabling evaluation of the optimum conditions of time, temperature, particle size, and pressure required in sintering to be made. A number of unsolved problems are also discussed.—G. F.

Designing Structural Parts for Powder Metallurgy. H. R. Clauser. (Materials and Methods, 1950, vol. 31, Apr. pp. 56–59). The feasibility of making a part by powder metallurgy depends largely upon whether or not the dimensions, shape, detail, and density can be obtained by pressing the powder in the die before sintering. The author describes in some detail the types of edge, section, hole, dimension, etc., which can be produced by powder methods, and illustrates the advantages of designing for the process by referring to two specific examples. These are a metal-powder padlock, made of an 80–20 leaded brass, pressed at between 30 and 50 tons/sq. in. and having a sintered density of 7·9–8·2 g./c.c., and a pair of gears $2\frac{7}{8}$ in. in dia. The gears are made of iron powder with 1% graphite, pressed at 40 tons/sq. in., and sintered at 2100° F., which gives a strength of 45,000 lb./sq. in.—P. M. C.

Precision Stainless Parts by Powder Metallurgy. A. J. Langhammer and P. Glick. (Iron Age, 1950, vol. 165, June 22, pp. 93–94). The Amplex Manufacturing Co., subdivision of Chrysler Corp., reports that it is now successfully making stainless-steel parts from powder; these include machine parts, bearings, and filters.—A. M. F.

Infiltration of Powder Metal Compacts with Lquid Metal. P. Schwarzkopf. (Metal Progress, 1950, vol. 57, Jan., pp. 64–68). To produce useful objects from powders of metals only slightly soluble in each other, the powder may be mixed, pressed, and sintered at a temperature high enough to melt the low-melting-point metal, or the lower-melting-point metal may be 'infiltrated' into a previously made porous compact of the higher-melting-point metal. The latter technique gives greater density, and hard strength, as is shown by experimental results with copper–iron mixtures.—R. A. R.

PROPERTIES AND TESTS

Russian Opinions on Evaluation of Metals by Mechanica Tests. E. P. Klier. (Metal Progress, 1950, vol. 57, Mar., pp. 358, 359, 372, 374, 375). This paper presents and discusses answers by nine Russian metallurgists to a series of questions put forward by the editors of *Zavodskaya Laboratoria*. The questions were in four groups dealing with: (*a*) The general character of mechanical properties; (*b*) evaluation of the structural behaviour of materials from the results of mechanical tests; (*c*) evaluation of the fabrication characteristics from the results of mechanical tests; and (*d*) quality control. The metallurgists were not in agreement in many of their answers.—R. A. R.

What Tensile Properties of Metals Mean in Design. J. B. Campbell. (Materials and Methods, 1950, vol. 31, June, pp. 49–51). The author gives a simple and clear explanation of the practical meaning of modulus of elasticity, yield strength, tensile strength, elongation, and reduction of area. Having described how these properties indicate respectively flexibility, maximum load-carrying capacity without permanent deformation, maximum load-carrying capacity without failure, and ductility, he discusses in some detail how they should be used for selecting metals and design.—P. M. C.

Strain Hardening of Mild Steel in the Torsion Test as a Function of Temperature. H. Larson and E. P. Klier. (American Society for Metals, Oct., 1950, Preprint No. 37). Two ship-plate steels showed ductility to a lower temperature with a torsion test than with a tensile test. The torsion data were converted to effective stresses and strains, and it is shown that $\sigma = K\delta^n$, where σ is the stress, δ the strain, K the strength coefficient, and n a strain-hardening exponent. Values for K and n agree with those from tensile tests, and n is shown to decrease with temperature.—E. T. L.

Reduction-of-Area Gauge Helps Determine Mechanica Properties of Metals at Low Temperatures. (Steel, 1950, vol. 126, Mar. 13, pp. 92–93). This paper describes a gauge developed by the American Bureau of Standards for use at temperatures from − 196° C. to + 100° C. The instrument consists essentially of one sliding and two fixed anvils connected through a lever mechanism to a dial gauge; it is accurate within 0·0001 in.—A. M. F.

Physics in the Iron and Steel Industry. I—Strength, Deformation and Flow of Materials. M. W. Thring. (Iron and Coal Trades Review, 1950, vol. 160, May 12, pp. 1068–1075). The primary purpose of this series is to show the rôle of physics in relation to metals and, in particular, to the manufacture and shaping of iron and steel. This introductory paper deals with the methods by which the fundamental properties needed to describe the behaviour of metals in all possible loading situations can be determined. Three branches of investigation are distinguished: (1) The engineering test: (2) the rheological description of the material; and (3) mechanism or theory. The paper deals mainly with the classification of the various tests in group (1), including tensile and compression tests, tests involving shear and tensile stresses, and dynamic tests, and with the classification of the physical coefficients necessary in group (2). An appendix describes an apparatus for demonstrating plasticity, elasticity, and work-hardening in a metal.—G. F.

Physics in the Iron and Steel Industry. II—Elastic Deformation. P. Feltham. (Iron and Coal Trades Review, 1950, vol. 160, June 2, pp. 1229–1233). The author discusses from

a theoretical viewpoint the stresses involved in the elastic deformation of a material. Uniaxial and biaxial stress systems are considered and resolved into separate components of hydrostatic stress and of shear and tensile stresses, and the Mohr-Rankine circle method of determining the shear and tensile stresses is described. The distribution of stresses at any point within a body subject to external stress is analysed, and examples are given of the method of determining the principal stresses in simple cases.—G. F.

Physics in the Iron and Steel Industry. III—Anelasticity of Metals. P. Feltham. (Iron and Coal Trades Review, 1950, vol. 160, June 16, pp. 1327–1329, 1333). The author describes the anelastic behaviour of metals, the most characteristic feature being the damping of mechanical vibrations, and explains the origin of anelasticity. Contributing grain-boundary effects are briefly surveyed, and examples are presented showing that the application of the theory of anelasticity can contribute to the understanding of many problems concerned with the microstructure of metals and alloys, and with their technical applications.—G. F.

Results of Stress Analysis Investigations Carried Out at Palermo University. J. Manzella. (Metallurgia Italiana, 1950, vol. 42, July, pp. 249–254). Brief details are given of the apparatus used. The author then reviews the results obtained after ten years of research (1938–48) on torsional stresses in shafts and stresses in perforated plates. The first investigations were carried out by means of electrical analogies and enabled useful data to be gathered on the shape factor of shafts with collars and having different diameters. By these methods it was also possible to determine the stress distribution in the neighbourhood of transition curves on the shaft and also the influence of key-ways. The second series of investigations was carried out by photo-elastic means with the object of obtaining a visual distribution of stresses.

M. D. J. B.

Fundamental Equations of the Elasto-Plastic State. S. dei Poli. (Costruzioni Metalliche, 1950, vol. 2, Sept.–Oct., pp. 16–20). [In Italian]. In the first part of this paper are discussed the fundamental relations which govern the behaviour of materials in the elasto-plastic range. A review is given of the analytical approaches made by various authors. In part two, a study is made of the variation in stress due to small deformations, and the results obtained are applied to the study of thin plates subjected to compression in this plane.

M. D. J. B.

The Use of the Photo-Elastic Method in Industry and Technology. J. T. Pindera. (Przeglad Techniczny, 1950, Sept.–Oct., pp. 457–467). [In Polish]. The photo-elastic method of stress determination and its applications in practice are described.—V. G.

Some Consequences of the Plastic Behaviour of Steels. F. Ranucci. (Costruzioni Metalliche, 1950, vol. 2, May–June, pp. 19–25). [In Italian]. The plastic behaviour of steels is briefly discussed and the theory outlined. A classification of the plastic properties of steels is given in relation to carbon content, and stress–strain diagrams are examined in relation to the behaviour of steels. Consideration is also given to factors affecting the design of girders in the plastic range. The author stresses the necessity for the practical engineer to become familiar with a theory and design procedure which must one day become standard practice.—M. D. J. B.

Electronic Instrumentation Applied to Engineering Research: Strain Measurement. R. K. Vinycomb. (Instrument Practice, 1950, vol. 4, Oct., pp. 661–666). The paper surveys American practice in electrical systems for the measurement of dynamic or varying strains. Magnetic and bonded resistance-wire strain gauges are described; full details are given of methods of attaching the wire gauges to test members, using nitro-cellulose cement and phenol resins. The measurement of the resistance changes where static or dynamic and static strains are to be recorded, is carried out on A.C. bridge instruments. Similar types of strain gauge are used as torquemeters, where the application of magnetic gauges overcomes the effect of slip rings on rotating shafts.—H. D. W.

A Multi-Channel String Galvanometer for Use with Wire-Resistance Strain Gauges. A. A. Wells. (Journal of Scientific Instruments, 1950, vol. 27, Mar., pp. 59–61). For simultaneous recording of dynamic strains with wire resistance strain gauges at moderate frequency response the string galvanometer, without amplification has the advantage of extreme simplicity, robustness, and portability. The theory and a full specification of the magnet, string, and optical requirements are given. Satisfactory results have been obtained under very severe field conditions.—H. D. W.

Some Effects of Quenching and Tempering on Residual Stresses in Steel. A. L. Boegehold. (Metal Progress, 1950, vol. 57, Feb., pp. 183–188). Comparison of internal stress in small test bar and actual components, due to phase-change volume changes, shows that stresses in the latter may be much greater. Tempering does not always reduce internal stress, and tests on 1 and 1½ in. rounds confirmed this on a range of steels. It is concluded that unfavourable residual stresses may be present after tempering and should be determined experimentally to make sure that the steel is being used to best advantage.—E. T. L.

Experimental Study of the Behaviour of Cylindrical Surfaces Axially Loaded. S. dei Poli. (Costruzioni Metalliche, 1950, vol. 2, Jan.–Feb., pp. 19–25). [In Italian]. Theoretically, if a thin cylindrical surface is compressed axially, a critical point will be reached above which the various stages of stable equilibrium will correspond to specific distortions in the surface. The author has set out to verify this qualitatively. A detailed description is given of the apparatus and materials used as well as the experimental method adopted. The results of the experiments are described at length and a number of diagrams are given showing the behaviour of the samples. The first fundamental result is that the deformation of surface is essentially elastic, notwithstanding the comparatively large corrugations (of the order of several millimetres). The second result is the remarkable agreement between test results and the theoretical forecast of load-strain behaviour.—M. D. J. B.

Steel Problems in Connection with Rail Manufacture. A. Wojcik. (Hutnik, 1949, vol. 16, Nov.–Dec., pp. 440–451). [In Polish]. In discussing the problems of the manufacture of rail steel the author relates different types of rail fracture to the composition, defects in ingots, and the melting process.

W. J. W.

Effect of Residual Stresses on Fatigue of Compressor Valves. E. W. P. Smith. (Metal Progress, 1950, vol. 57, Apr., pp. 480–481). Tests on heat-treatment of steel valves did not reveal the cause of weakness under repeated impact. It was then found that stress relief quadrupled the life, and avoidance of stress concentrations by cutting off sharp edges led to still greater improvement.—E. T. L.

Design and Construction of Equipment for a Small Stress-Rupture Creep Laboratory. F. C. Child. (Metallurgia, 1950, vol. 42, June, pp. 37–44). A description is given of the development and construction of miniature creep-testing machines for testing the creep properties at 900° C. of cobalt-base alloys. The specimens were heated in platinum-wound furnaces whose windings were divided into three zones. Temperature control was effected by means of a platinum resistance thermometer adjacent to and outside the furnace windings. The control mechanism was of an improved Prosser electronic type. It was eventually found possible to control the temperature of the specimens to within 1° C. for 1000 hours at 900° C. The temperatures of the specimens were read by means of platinum/platinum–rhodium thermocouples attached to them.

J. J.

Apparatus for the Measurement of Creep under Fluctuating Stress. W. R. Tyldesley. (Metallurgia, 1950, vol. 42, June, pp. 45–48). An apparatus is described for measuring the creep of a specimen which is subjected both to a static load, and also to stresses fluctuating at 100 cycles/sec. The fluctuating stress is generated by the force exerted on an iron core in the field of an alternating-current coil. The apparatus is of the horizontal type, and has been used in the determination of the creep properties of lead at room temperature under both constant stress and fluctuating stress conditions.—J. J.

Some Aspects of Graphitization in Steel. G. V. Smith, J. A. MacMillan, and E. J. Dulis. (American Society for Metals, Oct., 1950, Preprint No. 17). Graphitization has been studied by examining the effect of aluminium deoxidation, and of the heat-treatment atmosphere, on eutectoid carbon steels, heat-treated to give pearlitic or martensitic structures. Graphite was discovered by microscopical examination to form in the martensitic steel. The number of graphite nodules varies with austenitizing temperature, and it is indicated that the promotion of graphitization by aluminium deoxidation is due to residual aluminium.—E. T. L.

Formation of Oxides on Some Stainless Steels at High Temperatures. H. M. McCullough, M. G. Fontana, and F. H. Beck. (American Society for Metals, Oct., 1950, Preprint No. 4). A continuous weighing apparatus was used to study the course of oxide growth on three stainless steels (18/8s, 16% chromium, and 12·5% chromium respectively) between 815° and 980° C., in mixtures of oxygen and nitrogen. The rate of oxide growth increased abruptly after a steady growth, after 40, 20, and 10 min. respectively, because of the rupture of the scale. These times increased with the oxygen partial pressure, and with decrease in temperature. Pre-oxidation showed that $FeO.Cr_2O_3$ spinel is more protective than alpha Fe_2O_3.—E. T. L.

The Oxidation of Pure Iron. J. K. Stanley, J. von Hoene, and R. T. Huntoon. (American Society for Metals, Oct., 1950, Preprint No. 5). Within the range 500–900° C. weight gain W is given by $W^2 = Kt + C$ where t is time, C is a constant, and K is given by $K = 0{\cdot}37 \exp - 33{,}000/RT$ where R is the gas constant, and T the absolute temperature. The oxide films were investigated by X-rays, and Fe_3O_4 found at 500° C., with α-Fe_2O_3 and FeO also at higher temperatures, all of which remained intact on cooling to room temperature. There are 19 references.—E. T. L.

Nickel–Aluminium–Molybdenum Alloys for Service at Elevated Temperatures. H. V. Kinsey and M. T. Stewart. (American Society for Metals, Oct., 1950, Preprint No. 12). Test data on alloys of nickel, aluminium, and molybdenum show that these are as strong under tensile test as best cobalt-base alloys, at 815° C. The effect of composition on creep-rupture properties showed an optimum molybdenum content of 20–25% and the importance of a high ratio of nickel to aluminium. The effect of composition on the metallography was also studied. From all this tentative chemical specifications are advanced.—E. T. L.

Sigma-Phase Formation in a Wrought Heat-Resisting Steel. A. El Bindari, P. K. Koh, and O. Zmeskal. (American Society for Metals, Oct., 1950, Preprint No. 13). Using an apparatus involving a specimen supported by one arm of a balance in a magnetic field to detect sigma formation, also microhardness measurements, and X-ray analysis, it is shown that sigma phase can form in strain-hardened 18/8 steels, contrary to previous reports. Sigma forms in sites previously occupied by ferrite stringers. The authors suggest that sigma forms slowly from untransformed ferrite and austenite forms rapidly from ferrite in the range 760–870° C.—E. T. L.

A High-Sensitivity Torsion Creep Unit. A. E. Johnson. (Journal of Scientific Instruments, 1950, vol. 27, Mar., pp. 74–75). The torsion creep machine described provides a means of making creep measurements at stresses, due to subnormal temperatures, where the rates may be as low as 10^{-9} in./hr. A torsionmeter is used, the limbs of which are actually screwed into the ends of the test pieces. Provision is also made for carrying out stress relaxation tests.—H. D. W.

Effect of Cooling Rate and Composition on the Embrittlement of Weld Metal. E. C. Rollason and R. R. Roberts. (Journal of The Iron and Steel Institute, 1950, vol. 166, Oct., pp. 105–112). Tensile specimens of extremely rapidly cooled (*e.g.*, 1400° C./min.) mild steel weld metal have low ductility associated with woody fractures. In welds with high hydrogen content, micro-fissures similar to hair-line cracks are also found, and these prevent the complete recovery of ductility by tempering at 650° C. The extent of fissuring has been shown to be related to the hydrogen and nitrogen contents of the weld.

It is suggested that fissuring is caused by the embrittling effect of hydrogen on regions of the weld already reduced in ductility by the presence of carbon- and nitrogen-rich intermediate transformation products of austenite.

A study has been made of the effects, on fissuring and on nitrogen solubility, of alloy additions to weld metal. Rates of cooling sufficient to cause embrittlement are likely to arise in relatively few welding operations, but when welding thick plates under conditions liable to intensify the cooling of a weld, it is recommended that a preheat of 100° C. be used.

Gases and Steel. Sir Andrew McCance. (Institute of British Foundrymen: Iron and Coal Trades Review, 1950, vol. 160, June 9, pp. 1289–1297: Foundry Trade Journal, 1950, vol. 88, June 8, pp. 615–622). The author reviews the progress made in the study of the effects of gases on the properties of steel, dealing in particular with hydrogen and, to a lesser degree, with nitrogen from the steelfounder's viewpoint. The solubility of the gases in steel is discussed, and it is shown that the variation of the solubilities with temperature is consistent with the solution of solid compounds. The opinion is expressed that hydrogen plays an important part in the formation of both contraction cavities and blowholes, and other detrimental effects of high gas content are discussed. The various sources of hydrogen are considered, attention being given to ferro-alloys, rusty pig iron and scrap, and bath and ladle additions. The recarburizing additions of coke and anthracite are shown to produce considerable increases in hydrogen content, and the author advocates the practice of 'catching the carbon' in order to avoid their use. Improperly dried ladles and runners introduce appreciable quantities of hydrogen into the steel, and it is also suggested that scrap should be stored for a period before use in order to allow as much hydrogen as possible to escape.—G. F.

Titanium and Its Rôle in Steel Metallurgy. R. Skorski. (Hutnik, 1950, vol. 17, July–Aug., pp. 226–231). [In Polish]. Occurrence, properties, and methods of preparation of metallic titanium are described. The possible rôle of titanium in steel metallurgy, its influence on the iron–carbon system, the formation of a hypothetical compound sodium titano-nitride (NaTiN), and its possible use as a deoxidizing agent are discussed.—V. G.

Effect of 1150° F. Aging on Cr–Mo Steel Castings (2·5 to 9% Cr). N. A. Ziegler and W. L. Meinhart. (Metal Progress, 1950, vol. 57, Feb., pp. 203–207). A table gives values of the tensile properties of a wide range of chromium and molybdenum steels, with and without 2000 hr. ageing at 1150° F. Also the effect of this additional treatment on the microstructure is shown to be spheroidization of the carbide constituent, causing reduced strength, yield point, and hardness. However, the addition of nickel is not always an improvement.

E. T. L.

Use of Boron Steel in Production. F. J. Robbins and J. J. Lawless. (Metal Progress, 1950, vol. 57, Jan., pp. 81–89). Boron increases hardness of medium-carbon machining steels, and, for the particular 0·45% carbon steel studied, makes the alloy insensitive to heat-treating variations, and improves machinability.—E. T. L.

Effect of Alloying Elements on Notch Toughness of Pearlitic Steels. J. A. Rinebolt and W. J. Harris, jun. (American Society for Metals, Oct., 1950, Preprint No. 33). The effect on the Charpy V-notch toughness of a steel (0·30% C, 1·00% Mn, and 0·30% Si) of adding aluminium, boron, carbon, chromium, copper, manganese, molybdenum, nickel, phosphorus, sulphur, silicon, titanium, and vanadium, individually, has been investigated. The criterion of evaluation was the 'transition temperature,' chosen as the temperature where the impact energy equalled the average of the range of energies which a given steel needs for failure, over a wide range of temperatures. A statistical treatment of the results shows that manganese and nickel lower the transition temperature, whilst it is raised by boron, carbon, chromium, copper, molybdenum, phosphorus and silicon.—E. T. L.

The Influence of Chromium on the Mechanical Properties of Plain Chromium Steels. W. O. Binder and H. R. Spendelow, jun. (American Society for Metals, Oct., 1950, Preprint No. 23). Hardness, tensile strength, percentage elongation, and Izod impact strength have been determined as a function of the chromium content (in the range 0·3 to 55·0%) of annealed steels. It is found that the lowering of the impact strength with chromium by more than 20% is due to carbon and nitrogen. However, 0·10–0·25% nitrogen reduces the grain size and improves the ductility and impact strength, though not to the high level of alloys with little carbon or nitrogen.

E. T. L.

Statistical Analysis of the Effect of Alloying Elements on Mechnical Properties of Seamless Steel Tubes. W. T. Rogers. (American Society for Metals, Oct., 1950, Preprint No. 41). A multiple regression analysis of yield strength, tensile strength, and elongation results for seamless steel tubes, with respect to carbon, manganese, phosphorus, silicon, titanium, and molybdenum content, gives a set of equations for values of each of these mechanical properties for a particular steel composition. This set of equations shows, for instance, the predominant effect of phosphorus in increasing the yield strength, and neglects interactions of elements. The equations have been tested in two years' practice.—E. T. L.

METALLOGRAPHY

The Exhibition of Scientific Testing Apparatus. L. Bobrowski. (Przeglad Techniczny, 1950, Sept.–Oct., pp. 439–446). [In Polish]. A description is given of apparatus such as microscopes, magnetic powder testers, X-ray equipment, and spectrographs produced by countries of Eastern Europe.

Optical Micrography. J. Ternisien. (Microtecnic, 1949, vol. 3, May–June, pp. 134–139; July–Aug., pp. 165–173; Sept.–Oct., pp. 225–231; Nov.–Dec., pp. 280–288). The author discusses micrography with transmitted and with reflected light. The principles are explained, and many instruments described and illustrated.—R. A. R.

Room-Temperature Casting Resin for Mounting Metallographic Specimens. J. S. Church and G. L. Kehl. (United States Atomic Energy Commission, Technical Information Division, 1946, MDDC-94). The method of casting methyl metacrylate menomer for mounting metallographic specimens is as follows: A micarta ring, $\frac{3}{4}$ in. inside dia. × 1 in., is placed with its edge in contact with a glass plate, the specimen is placed inside it and sufficient resin to cover the specimen, plus 50% to allow for shrinkage, is cast over it. The mould is placed under ultra-violet light and maintained at about 50° C. Properly prepared resin will harden under these conditions in 2 to 3 hr. Additional resin may be added in increments.—R. A. R.

Rigid Tests Check Quality of Pressure Welds in Low Alloy Steels. A. I. Nussbaum. (Materials and Methods, 1950, vol. 31, May, pp. 80–82). The Menasco Manufacturing Co. (U.S.A.), produces aircraft landing gear, in the fabrication of which great use is made of the oxy-acetylene pressure-welding technique. The quality of these welds is checked by a bend test on a welded tube, and by a simulated service test in which a complete landing assembly is loaded in a special 'drop tower.' Details of this latter test are not given. Microscopical examination is also carried out to reveal any oxygen segregation, which is considered to be detrimental. For this purpose an alkaline chromate etching reagent has been developed, the composition and use of which are fully described.—P. M. C.

A Report on Recent Research in Electrolytic Polishing. P. Michel. (Sheet Metal Industries, 1949, vol. 26, Oct., pp. 2175–2189; 1950, vol. 27, Feb., pp. 165–173). The theory of electrolytic polishing is explained and electrolytes, factors affecting the polishing process, the macro- and microstructures, and properties of the surfaces produced are discussed on the basis of laboratory tests at the Renault works.—R. A. R.

The Production of Geometrically Accurate Shapes by Electrolytic Polishing. P. Michel. (Sheet Metal Industries, 1950, vol. 27, Mar., pp. 267–271). Investigations are described which show that it is possible by the use of suitable cathodes, bushes, and screens to obtain accurate cylindrical polished surfaces by electrolytic polishing.—R. A. R.

18-8 Stainless Now Easily Classified. O. J. Winkle. (Iron Age, 1950, vol. 165, June 29, pp. 76–78). The Douglas Aircraft Co. has developed a method for differentiating between stabilized and unstabilized 18/8 steels. Carbide precipitation is induced in the specimen by heating to 1560° F. for 3 hr., cooling to 1000° F. and then water, air, or furnace cooling; pickling in a bath of 15–18% nitric acid and 0·75% hydrofluoric acid then follows. Stabilized samples show little change, but unstabilized samples are subject to severe intergranular attack.—A. M. F.

Carbides in Long-Tempered Vanadium Steels. W. Crafts and J. L. Lamont. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 561–574; Journal of Metals, 1950, Mar.). An electron microscope study of the carbides in vanadium–chromium–molybdenum steels tempered for up to 1000 hr. at temperatures ranging from 315° to 760° C. is described, and electron micrographs of the various structures are presented. Martensite is shown to decompose initially into a plate-like structure containing carbide of the Fe_2C type, which on further tempering changes to the Fe_3C type. It is confirmed that alloy carbides are formed at the secondary hardening temperature by decomposition of the plate-like iron carbides, secondary hardening being developed to the anticipated degree. Vanadium carbide is shown to persist as smaller particles than either the chromium-bearing or molybdenum-bearing carbides, indicating that conditions of heat-treatment and composition conducive to the formation of the fine vanadium carbides are favourable for high-temperature strength.—G. F.

Diffusion Coefficient of Carbon in Austenite. C. Wells, W. Batz, and R. F. Mehl. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 553–560; Journal of Metals, 1950, Mar.). The determination of the values of the diffusion coefficient of carbon in austenite, by statistical computation, is described, and graphs of the results are presented covering the temperature range 750–1300° C. and the composition range 1–7% (atomic) carbon. The diffusion coefficient D, the activation heat of diffusion Q, and the constant A in the diffusion equation $D = Ae^{-\frac{Q}{RT}}$ are each related to the carbon concentration; as the concentration increases, D is found to increase first slowly and then more rapidly, whilst Q and A are found to decrease. The values of D are computed by the methods of Matano and of Grube, and it is shown that the provision in Matano's equation for taking into account the variation of D with concentration is justified.—G. F.

On the Theory of Diffusion in Metals. F. Seitz. (Acta Crystallographica, 1950, vol. 3, Sept., pp. 355–363). Zener has generalized the interchange mechanism of metallic diffusion by considering interchange processes in which more than two atoms may change places at once. The position of these calculations relative to those of Huntingdon and Seitz on the mechanism of diffusion is discussed. It is emphasized that the calculations still favour the vacancy mechanism, although the purely theoretical support is not as overwhelming as it seemed to be previously. The experimental situation is reviewed. It is pointed out that the existing experiments on the Kirkendall effect, which is concerned with the motion of fiducial markers during diffusion, and the diffusion of minor additions in substantial alloys strongly support either a vacancy or interstitial mechanism and exclude a direct interchange mechanism as the major contributing process. Taken as a whole the theoretical and experimental evidence supports the vacancy mechanism as previously. Bardeen's derivation of Darken's relations between the chemical diffusion coefficient and the diffusion coefficients of individual atoms is examined somewhat more generally in the appendix.—E. T. T.

Ring Diffusion in Metals. C. Zener. (Acta Crystallographica, 1950, vol. 3, Sept., pp. 346–354). The concept of hole migration in metals as the mechanism of self-diffusion and of diffusion of substitution-solute atoms has arisen from the apparent failure of other reasonable mechanisms, such as direct interchange, to give heats of activation comparable to those observed. In this paper it is pointed out that diffusion by direct interchange is only a special case of diffusion by the synchronized cyclic motion of a number of atoms, herein called 'ring diffusion.' General arguments are presented demonstrating that a 4-ring has a lower potential-energy barrier for cyclic motion than has a 2-ring, which corresponds to direct interchange. These general arguments are supported by detailed calculations for the particular case of self-diffusion in copper. It is concluded that such ring diffusion is not excluded by energy considerations.—E. T. T.

The Growth of Austenite as Related to Prior Structure. A. E. Nehrenberg. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 162–164; Journal of Metals, 1950, Jan.). A description is given of an investigation into the directional growth of austenite in a total of 15 steels, consisting of eutectoid carbon steels and hypo-eutectoid and hyper-eutectoid carbon and alloy steels. It is shown that the growth of new austenite is restricted by the initial grain boundaries, and that it first assumes the size and shape of these grains. The new austenite is equiaxed when the initial structure is the result of high-temperature transformation, and is acicular in shape when the initial structure is bainitic or martensitic. Photomicrographs illustrating the growth of the austenite in the series of steels under the various conditions of treatment are given. G. F.

Self-Diffusion in Alpha and Gamma Iron. C. E. Birchenall and R. F. Mehl. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 144–149; Journal of Metals, 1950, Jan.). A description is given of a study of self-diffusion in α- and γ-iron. Measurements of self-diffusion coefficients over the temperature range 720–1357° C. are presented, and it is shown that at the temperature of transformation, the self-diffusion coefficient for α-iron is about 660 times greater than that for γ-iron. The activation

energies in the two phases are shown to be in agreement, and the data also agree well with the rates of diffusion of molybdenum, manganese, and nickel in dilute solution in iron. A grain-size effect in the lower temperature studies is noted.
G. F.

Fracturing of Silicon-Ferrite Crystals. C. F. Tipper and A. M. Sullivan. (American Society for Metals, Oct., 1950, Preprint No. 30). Neumann lamellæ formation, associated with cleavage fracturing, was studied in tensile tests on a 3·5% silicon ferrite having large grains of similar orientation. Neumann lamellæ were not observed to form, except in conjunction with the cleavage type of fracturing. It is shown that Neumann lamellæ are unlikely origins or causes for cleavage, but that shock loading accompanying discontinuous cleavage may cause them to form. X-ray verification was made of cleavage on the (100) and (112) planes. There are 23 references.—E. T. L.

The Alloy Systems Uranium–Aluminium and Uranium–Iron. P. Gordon and A. R. Kaufmann. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 182–194; Journal of Metals, 1950, Jan.). An investigation into the systems uranium–aluminium and uranium–iron is described, in which a series of alloys of the two systems was prepared in beryllia crucibles in an induction furnace, either under vacuum or in an atmosphere of argon. Photomicrographs of the alloys in different stages of heat-treatment and X-ray diffraction data are presented and discussed, and a brief description of the inverse rate method of determining the cooling curves of the alloys is given. The equilibrium diagrams for the two systems obtained from the results are presented, showing that in each case several intermetallic compounds occur and that the solid solubility in the terminal phases is very limited.—G. F.

The System Chromium–Carbon. D. S. Bloom and N. J. Grant. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 41–46; Journal of Metals, 1950, Jan.). An investigation of the chromium–carbon system, up to 20% carbon, using metallographic, X-ray, and thermal analysis methods is described. A phase diagram for the system is presented, indicating that some of the transformation temperatures pertaining to the three known carbides Cr_4C, Cr_7C_3, and Cr_3C_2 are higher than those obtained in other investigations of the system, whilst the melting point of pure chromium is found to be 1930° C. Several attempts, all unsuccessful, to produce the carbide 'CrC' are also described.—G. F.

CORROSION

Corrosion. R. Clark. (Canadian Metals, 1950, vol. 13, July, pp. 38, 40). The author reviews iron and steel losses through rust, and mentions de-odourized, pre-oxidized fish oil as a quick-drying rust preventor, applicable to clean, dirty, or rusty surfaces.—E. C.

What You Should Know about Corrosion of Ferrous Metals. G. D. Lain. (Steel, 1950, vol. 126, Mar. 13, pp. 101–104). Corrosion is divided into the following classifications dependent on the surrounding media, atmospheric, bacterial, chemical, high-temperature oxidation, soil, stray electrolysis, and underwater. A short description of each type, together with preventive methods that can be taken, is given. The question of the reversal between steel and zinc in the electrochemical series is discussed.—A. M. F.

Galvanic Corrosion—What It Is and How It Can Be Avoided. S. B. Ashkinazy and J. M. Joyce. (Materials and Methods, 1950, vol. 31, Feb., pp. 49–53). Galvanic, or electrochemical corrosion, occurs when dissimilar metals are in contact in the presence of moisture. The mechanism of this type of corrosion is fully explained and the factors which influence its progress are discussed. Of these, the positions of the metals in the Electromotive Series are the most important, and a special table has been compiled which takes into account certain practical complications, such as the tendency of some metals to form protective coatings. Of the common production materials, magnesium alloys and aluminium are the least noble, and therefore most susceptible to corrosion. Practical measures which will minimize the effect are outlined in some detail.—P. M. C.

Electrochemical Behaviour of Zinc and Steel in Aqueous Media—Part II. R. B. Hoxeng. (Corrosion, 1950, vol. 6, Sept., pp. 308–312). It is shown that the addition of even small amounts of calcium to water shifts the potential of zinc immersed in it in the anodic direction. Silicate additions have the same effect, thus tending to reduce the possibility of reversals in zinc–steel couples. Earlier evidence that temperature is secondary to electrolyte composition in its effect on the electrochemical behaviour of zinc is confirmed. (For Part I *see* Journ. I. and S.I., 1950, vol. 165, May, p. 124.)
O. H. G.

Corrosive Behaviour in Very Dilute Aqueous Solutions. III—Corrosion at Temperatures below 100°. L. W. Haase. (Werkstoffe und Korrosion, 1950, vol. 1, Apr., pp. 129–132). Continuation of a series of articles (*see* Journ. I. and S.I. 1948, vol. 158, Feb., p. 286). Corrosion phenomena in all the tests at temperatures in the 20–100° C. range were mainly attributable to the higher reaction capacity at the increased temperature. The actual causes of the corrosion in warm water are: (*a*) the conversion of the atomic hydrogen into the molecular state; (*b*) the transfer of oxygen from the 'really dissolved' to the 'pseudo-dissolved' state; and (*c*) oxygen depolarization is ineffective at the increased temperature.—R. A. R.

Polarographic Study of Corrosion Phenomena. P. van Rysselberghe, J. M. McGee, A. H. Gropp, R. D. Williams, and P. Delahay. (Corrosion and Material Protection: Corrosion, 1950, vol. 6, Mar., pp. 105–113). The use of the polarograph in the study of the fundamental physical chemistry of corrosion is described. The method has been used to determine the consumption by metals and alloys of oxygen, of carbon dioxide, of hydrogen peroxide, of oxygen and carbon dioxide simultaneously, and of hydrogen peroxide and carbon dioxide simultaneously; and also for the investigation of the possible rôle of hydrogen peroxide and of percarbonic acid in corrosion. Experimental technique and analysis of polarograms are described.—O. H. G.

Corrosion of Bare Iron or Steel in Sea Water. J. C. Hudson. (Journal of The Iron and Steel Institute, 1950, vol. 166, Oct., pp. 123–136). The results so far obtained in the course of the Corrosion Committee's work relating to the corrosion of structural irons and steels when immersed in sea water are presented and critically examined. The presence of millscale on the iron or steel is shown to promote serious pitting in sea water. The rate of general corrosion of mild steel when immersed in British waters after removal of the millscale is found to be approx. 3–5 mils/year. There is little, if any, difference in the corrosion rates, under these conditions, of ordinary unalloyed ferrous materials, such as mild steel, ingot iron, or wrought iron. Of a wide range of alloying elements incorporated in a series of low-alloy steels, only two, chromium and nickel, are shown to have any significant effect in reducing the corrosion rate. Steels containing 2–3% of chromium were found to corrode at one-half or one-third of the rate of unalloyed steels of the same carbon content. The effect of nickel additions was less marked. No significant difference has been observed in the behaviour of ordinary and of copper-bearing steels when totally immersed in sea water.

Cathodic Protection of an Active Ship in Sea Water. K. N. Barnard and G. L. Christie. (Corrosion, 1950, vol. 6, July, pp. 232–234). H.M.C.S. "New Liskeard," a 225-ft. minesweeper of 960 displacement tons on active duty with the Royal Canadian Navy, has been fitted with a cathodic protection system using magnesium alloy anodes. In June 1949, ten magnesium alloy anodes, 3 in. × 7 in. × 60 in., weighing about 80 lb. each, were secured to the bilge keels but insulated from the steel of the hull. Hull potential readings with respect to a silver–silverchloride electrode in sea water show that the hull is protected while at rest. Under way, the degree of polarization decreases slightly. By securing the anodes on the bilge keel there appears to have been a loss in effectiveness caused by uneven distribution of current with varying distance from the anode. Results to date indicate cathodic protection of an active ship of this size is an economic and practical proposition. (*See* Journ. I. and S.I., 1949, vol. 161, Apr., p. 393).—O. H. G.

Corrosion of Steel Pipe by Chlorinated Seawater at Various Velocities. V. B. Volkening. (Corrosion, 1950, vol. 6, Apr., pp. 123–128). Corrosion rates of steel pipe in sea water were obtained for six residual chlorine concentrations ranging from 0 to 4·0 p.p.m. at five sea-water velocities from 0·1 to 6·4 ft./sec. Pitting rates were accurately measured and compared with weight-loss corrosion data. The minimum

effective dosage of chlorine was determined for eliminating marine fouling organisms. A simple and accurate method for the determination of residual chlorine in sea water is also discussed.—O. H. G.

Fluorine Corrosion: (A) High-Temperature Attack on Metals by Fluorine and Hydrogen Fluoride; and (B) Behaviour of Insulated Steel Parts in Fluorine Cells. W. R. Myers and W. B. DeLong. (United States Atomic Energy Commission, 1947, MDDC 1465). Nickel and Monel metal show good resistance to fluorine at temperatures up to 500° C. Carbon steels with less than about 0·01% of silicon are resistant up to about 400° C. The stainless steels, except Type 347, resist satisfactorily up to 250° C. The anodic corrosion of steel in $KHF_2.HF$ at 90° C. increases rapidly with potential drops above approximately 5 V.—R. A. R.

Influence of Deformation by Piobert Lines on the Attack of Iron by Cathodic Hydrogen. J. Duflot and G. Chaudron. (Comptes Rendus, 1950, vol. 231, Sept. 25, pp. 620–621). Pitting in the area of Piobert (Lüders) lines is only visible under the lens after hydrogen attack. After attack these areas only give off about half as much hydrogen as undeformed parts. Impurities are not thought to be the cause. Piobert lines may lessen the larger imperfections in the lattice.—A. G.

Present Knowledge of Low-Carbon 18–8. H. W. Gillett. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 41–54). A review is made of the literature on austenite stability, carbide precipitation, weldability, and corrosion resistance of low-carbon 18/8 chromium–nickel stainless steels. It is pointed out that to provide absolute immunity from precipitation and grain-boundary corrosion, impracticably low carbon and nitrogen contents must be assured. The effects of titanium, columbium, copper, manganese, silicon, molybdenum, and boron are also discussed, together with the effects of grain size and rolling reduction in relation to the above problems. The value of various acceptance tests in use is reviewed. There are 46 references.—J. J.

Corrosion Resistance and Mechanical Properties of Low Carbon Austenitic Stainless Steels. D. C. Buck, J. J. Heger, F. J. Phillips, and B. R. Queneau. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 56–80). An exhaustive series of tests was carried out on samples of 18/8 steels made in 30-ton arc furnaces. These steels were all of the low-carbon type (0·030% C max.) with or without the addition of columbium, molybdenum, or columbium and molybdenum. The tests performed included corrosion resistance to copper sulphate plus sulphuric acid, and nitric acid reagents after various heat-treatments. Room-temperature tensile tests and high-temperature creep tests were performed together with low-temperature impact tests. The results of tests on welded samples show that these low-carbon 18/8 steels are satisfactory substitutes for titanium and columbium stabilized grades for welding and similar applications.—J. J.

Accelerated Corrosion Testing of Chromium–Nickel Stainless Steel Weldments. F. K. Bloom and M. E. Carruthers. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 87–100). Accelerated corrosion tests on metal-arc welded specimens of 0·06 and 0·03% max. carbon, chromium–nickel stainless steels were conducted in hot nitric plus hydrofluoric acids, boiling 65% nitric acid and boiling copper sulphate plus sulphuric acid solution. The results are compared with field experience with a welded pickling tank where both types of alloy were used. The three common corrosion tests differ markedly in their attack on heat-affected weld zones. The nitric–hydrofluoric acid test appears to be the most severe criterion of susceptibility to weld decay. Service results, where the corrosive conditions were severe, compared well with laboratory tests and confirmed the fact that the 0·03% max. carbon alloys are free from harmful carbide precipitation in the as-welded condition.—J. J.

An Appraisal of Methods for Evaluating the Corrosion Resistance of Stainless Steels. M. H. Brown, W. B. DeLong, and W. R. Myers. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 103–119). Tests were performed on four different types of very low carbon 18/8 steels and similar steels with molybdenum, to determine their corrosion resistance. The tests were made using boiling 65% nitric acid, acidified copper sulphate solution, and a nitric-hydrofluoric acid mixture. The results obtained by the three methods agreed quite well with each other except in the case of the steels containing molybdenum. Data from nitric acid tests extending over 20 years for several types of stainless steel are examined statistically, and studied in the light of the performances of the steels concerned under very many different conditions. It is concluded that the nitric acid test is a valuable one in assessing the resistance of stainless steels to intergranular corrosion. J. J.

Some Observations on Tests for Intergranular Susceptibility of 18/8 Mo Stainless Steels. H. Ebling and M. A. Scheil. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 121–138). The authors intend to focus attention on the tests used to determine the susceptibility to intergranular attack of stainless alloys. It is pointed out that a large number of variables exist in the present testing practice and that a standard practice should be inaugurated. Using an acidified copper sulphate solution, a series of tests was made on type-316 steels to determine the effects of the stabilizing heat-treatment temperature (1550° to 1650° F.) stabilizing heat-treatment time, and the cooling rate. It is shown that the cooling rate after stabilizing is important since it can affect the sensitization of the alloy. Another series of tests was made to study the effects of sensitizing type-316 steels to 800° and 900° F. for 500 hr. after the stabilizing heat-treatment. In these tests the regular type-316 alloys failed. However, most of the low carbon (0·03% carbon max.) type-316 steels sustained the sensitizing treatment at 800° and 900° F. for 500 hr. and exhibited immunity to intergranular attack. Some tests were made on type 316-Cb in order that some comparison could be made with the low carbon type 316. In further tests specimens of low carbon type-316 and type 316-Cb were sensitized at 900° and 1020° F. for times up to 1000 hr. The results show that the low carbon type-316 alloy will sensitize at the low temperature if held for a sufficient length of time.—J. J.

Influence of Carbon and Molybdenum on the Intergranular Corrosion Resistance of Austenitic Chromium–Nickel Steels With and Without Columbium. W. O. Binder and C. M. Brown. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 146–171). Comparative intergranular corrosion tests have been made on five types of 18/8 steel containing 0·06 and 0·03% max. carbon, including the molybdenum and molybdenum–columbium variations. The data show that the increased corrosion rate noted in 65% boiling nitric acid must be ascribed to a phase formation other than chromium carbide precipitation when molybdenum is present in steels containing about 0·03% of carbon or sufficient columbium to combine with all the carbon. A study of steels containing 0·01% max. carbon indicates that the phase is sigma. The phase has been found to be most damaging to corrosion during its formative period when it exists as an envelope of fine particles around the austenite grains. Although the steel in this condition is subject to intergranular attack by strong nitric acid, it is resistant to such media as boiling acidified copper sulphate, mixed nitric and hydrofluoric acids, and air-free sulphuric acid. Prolonged heating at 750° C. which coalesces the particles, restores the resistance of the steel to intergranular attack in nitric acid. Of the two causes of intergranular attack noted in the molybdenum-bearing 18/8 steels, the precipitation of chromium carbide appears to be the more dangerous. It has produced susceptibility to intergranular attack in both reducing and oxidizing acids, whereas the effect of the intermetallic compound has been observed only in nitric acid. The nitric acid test reveals both types of intergranular attack. To distinguish between these two causes in assessing molybdenum steels for service, the nitric acid test should be supplemented by at least one other intergranular corrosion test to ensure that a high corrosion rate in nitric acid does not prejudice the use of the steels in reducing acid media, if the attack is due to the formation of the sigma phase.—J. J.

Comparative Corrosion Resistance of Stainless Steels in Various Acids. R. B. Mears, C. P. Larrabee, and C. J. Fetner. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 183–187). The

corrosion resistance of several grades of austenitic stainless steels was determined in the boiling nitric acid test and compared with their corrosion resistances in sulphuric acid solutions. Steels which showed the least corrosion resistance in the nitric acid generally proved to be the most resistant to sulphuric acid. Specimens of two types of stainless steel were exposed in the annealed and the sensitized state to tests by boiling nitric acid, and boiling solutions of lactic, phosphoric, and acetic acids. Type-316 steel was less resistant to nitric acid, but more resistant to the other boiling acids, in most cases, than the type-304 steel. Microscopical investigation showed that the type of attack developed in nitric acid by the annealed or sensitized 316 or 304 steel was qualitatively the same as the attack in the other acids provided that any attack developed.—J. J.

Comparison of Plant Corrosion Test Results on Austenitic Stainless Steels with Results of Huey and Strauss Tests. H. O. Teeple. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 192–199). Data are presented on the resistance of some of the austenitic stainless steels to corrosion by media encountered in the chemical and processing industries in relation to their performances in the Strauss and Huey tests. The plant corrosion data, obtained by exposing specimens in many different corrosive media on plants are tabulated. Unwelded, as-welded, and welded and heat-treated specimens of stainless steels types 304, 316, and 347 were used. Some tests were also made of the all-welded specimens of the 0·03% max. carbon type 316 stainless steel. The same steels with various heat-treatments were subjected to Strauss and Huey tests in the laboratories and the results of these are tabulated alongside the plant corrosion data. The specific compositions of the alloys used are also tabulated.—J. J.

Results of Some Plant Corrosion Tests of Welded Stainless Steels. G. F. Comstock. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 200–209). Corrosion tests on welded stainless steels were made in a number of chemical plants under regular operating conditions, and results are compared with those obtained on the same steels tested by the standard boiling nitric acid procedure in the laboratory. The specimens included type 304, 321, and 347 sheets welded with type 308, 321, and 347 electrodes, respectively. They were tested in the as-welded and stress-relieved states. The results show no correlation between the plant tests and the standard nitric acid test. In the former there were no significant differences between the results on type-321 and type-347 steels.—J. J.

Testing Multiple Specimens of Stainless Steels in a Modified Boiling Nitric Acid Test Apparatus. W. B. De Long. (American Society for Testing Materials, 1949, Special Technical Publication No. 93, pp. 211–214). An apparatus is described for carrying out corrosion tests on stainless steels in boiling nitric acid which is claimed to have advantages over the ordinary technique of using 1000-ml. Erlenmeyer flasks. It is shown that the test as ordinarily performed is unsatisfactory because the rate of corrosion is accelerated by chromium ions which accumulate in the solution. The apparatus described exposes the specimens to a continuously circulating condensate of acid, as in a Soxhlet extraction apparatus, whereby the acid in contact with the specimens is free from accumulated ions in solution. In this way, batches of samples can be tested together without mutual interference. Tests carried out on the apparatus, showing the advantages accruing from its use, are described.—J. J.

Action of Corrosion and Stress on 13% Cr Stainless Steel. H. H. Uhlig. (Metal Progress, 1950, vol. 57, Apr., pp. 486–487). For corrosion cracks in stressed surfaces, at least a certain stress, and a corroding medium are necessary. Experiments show that some stainless steels corrode in a way different from austenitic stainless steels. Electrolytic attack with various electrolytes revealed that the cracking of these martensitic stainless steels is by a process like hydrogen embrittlement.—E. T. L.

Cast 12% Chrome Steels Proved in Gas Wells. J. W. Juppenlatz. (Iron Age, 1950, vol. 165, June 22, pp. 85–89). Tests have been carried out with various percentages of nickel and chromium in steel to combat corrosive attack in gas wells. The corrosion is probably due to organic acids and is aggravated by pressures of from 2000 to 8000 lb./sq. in. and temperatures of 135° F. For valve fittings it is found that 12% chromium steel castings give satisfactory service, the high yield point of 50,000–160,000 lb./sq. in. being ideal for high pressure application.—A. M. F.

Field and Laboratory Tests of Sodium Chromates and Alkalies for Controlling Corrosion in Gas Condensate Wells. C. K. Eilerts, R. V. Smith, F. G. Archer, L. M. Burman, F. Greene, and H. C. Hamontre. (Corrosion, 1950, vol. 6, Apr., pp. 131–136). The paper describes work done by the U.S. Bureau of Mines. Low concentrations of the inhibitor in the water phase of the flowing fluid reduce rates of corrosion in the flowstring to negligible values. In some wells and fields it is necessary to prevent chemical reduction to insoluble hydrous chromic oxide. This may be done by maintaining a high *p*H value by injecting alkalis, and by keeping the chromate concentration low. The method is judged to be efficient and economical.—O. H. G.

The Behaviour of the Chromium Nickel Stainless Steels in Sulphuric Acid. G. C. Kiefer and W. G. Renshaw. (Corrosion, 1950, vol. 6, Aug., pp. 235–244). The corrosion rate of four commercial chromium–nickel stainless steels and one special type in sulphuric acid of varying concentration from 0 to 95% at temperatures of 38°, 65°, 80°, and 93° C. has been studied. At about 65° C. all the steels studied remained active in almost all acid concentrations. Below this temperature molybdenum-bearing steels were most resistant, and increasing chromium content had some effect in lowering the corrosion rate. The addition of copper to molybdenum-bearing steels improved resistance, but these steels did not show a sharp passive-active boundary. The addition of various inorganic sulphates to the acid caused a lowering in corrosion rates. The addition of oxidizing agents such as nitric or chromic acid completely inhibited attack, and there were indications that attack is also completely inhibited by the addition of the sulphates of all metals below chromium in the electropotential series.—O. H. G.

The Corrosion of the Austenitic Stainless Steels. Part I—Types of Stainless Steel and Forms of Attack. Part II—Pitting and Intergranular Corrosion. Part III—Stress Corrosion. Part IV—Effect of Alloying Elements and of Corrosive Media. G. T. Colegate. (Metallurgia, 1950, vol. 41, Jan., pp. 147–150; Mar., pp. 259–262; Apr., pp. 305–308; May, pp. 362–366). The corrosion resistance of the austenitic stainless steels (chromium 16 to 25%, nickel 6 to 22%, with or without other alloying elements) is discussed. Stainless steel is more liable to attack if the surface is rough or contaminated with soil of various kinds than if it is clean and well polished. Embedded metallic or non-metallic materials can generally be removed by a nitric acid dip at a moderately elevated temperature. It is impossible to give a list of solutions in which stainless steel remains passive because temperature, concentration, purity, and composition of the steel all have an effect in determining the width of any passive range. When relatively small areas of stainless steel have been used in conjunction with larger areas of carbon steel in sea water, no attack whatever is suffered by the former, and the accelerated attack on the latter is not sufficiently serious to be of any practical consequence.

The conditions likely to cause pitting and intergranular corrosion are discussed. The following methods of preventing pitting are mentioned: Maintaining oxidizing conditions as uniform as possible; avoidance of the presence of the chloride ion; increasing the *p*H of the medium; and designing vessels without recesses or pockets where stagnant liquid can accumulate. Intergranular corrosion can be prevented by: Annealing between 1050° and 1100° C. followed by a rapid quench; keeping the carbon content very low; and making additions of titanium or niobium.

Transcrystalline cracking is the most frequently encountered and the most difficult to explain. The solution most often used to test the susceptibility to stress corrosion is one containing 42% magnesium chloride. The effects of molybdenum, silicon, copper, selenium, and sulphur on the corrosion resistance, the behaviour of stainless steels in sulphuric, sulphurous, hydrochloric, hydrofluoric, and organic acids, and in contact with alkalis, food products, natural waters, non-aqueous liquids, and gases are all discussed.—R. A. R.

Corrosion of Molybdenum-Bearing Stainless Steel Weld Metals. A. L. Schaeffler and R. D. Thomas, jun. (Welding Journal, 1950, vol. 29, Jan., pp. 13s–24s). Weld metals of the stainless steels 316, 317, 318 (316 Cb) and extra low

carbon 316 have been subjected to boiling 65% HNO_3 and boiling copper-sulphate–H_2SO_4 solution. Corrosion rates in boiling HNO_3 were consistently low only after a quench-annealing heat-treatment. Intergranular carbide precipitation in types 316 and 317 accounted for high rates of corrosion in specimens treated at 1200° and 1300° F. Intergranular sigma-phase precipitate probably caused the high rates observed in columbium-bearing types 318 and 316 (0·03% C). During heat-treatment at 1300° or 1550° F. any ferrite present transformed to sigma, thus lowering the ductility of weld metal, and this type of sigma-phase remained relatively unattacked by HNO_3. In the as-welded condition results varied considerably depending on type and location of carbide and sigma-phase precipitates. In a 500-hr. test using boiling Cu_2SO_4–H_2SO_4 solution specimens showing intergranular carbides gave high rate of corrosion. Weld metal type 318, and extra low carbon type 316 showed no attack.—U. E.

Use of Magnetic Field in Detecting Corrosion Currents. F. Blaha. (Nature, 1950, vol. 166, Oct. 7, p. 607). A drop of dilute KCl solution on one iron pole-piece of an electromagnet rotates due to currents caused by differences in oxygen concentration at the centre and periphery. Only the centre is corroded. A rough estimate of current strength can be made from the velocity of rotation.—A. G.

The Mechanism of Inhibition of the Corrosion of Iron by Sodium Hydroxide Solution. J. E. O. Mayne, J. W. Menter, and M. J. Pryor. (Journal of the Chemical Society, 1950, Nov., pp. 3229–3236). When iron, freed from its original air-formed oxide skin, is immersed in 0·1 *N* sodium hydroxide containing dissolved oxygen, it becomes covered with a thin film of γ-Fe_2O_3. The view is put forward that this film is responsible for passivity and results from a heterogeneous reaction between oxygen dissolved in the solution, and the iron. A de-aerated solution of 0·1 *N* sodium hydroxide attacks iron very slowly; the reaction is controlled mainly by high polarization of the cathodic discharge of hydrogen ions.

A Rust-Preventing Pickling Inhibitor. K. F. Hager and M. Rosenthal. (Corrosion, 1950, vol. 6, July, pp. 225–231). A brief review is given of the properties of inorganic inhibitors (metal salts having a relatively high overvoltage) and of organic inhibitors (hydrocarbon–nitrogen–oxygen–sulphur compounds which are adsorbed on the cathode area and thus protect metal). A new inhibitor, Emulphor STH, is described. This is a wetting agent, and is characteristic of a new class of organic inhibitors which combine excellent inhibiting properties with a sustained rust-preventing effect on highly active freshly pickled surfaces. Weight-loss and hydrogen-evolution experiments with Emulphor STH simulating industrial conditions are described.—O. H. G.

Corrosion of Metals in Fluorine and Hydrofluoric Acid. G. C. Whitaker. (Corrosion, 1950, vol. 6, Sept., pp. 283–285). Previous work is reviewed and experience gained by the Harshaw Chemical Company, Cleveland, Ohio, in handling hydrofluoric acid and fluorine in steel and nickel vessels is described.—O. H. G.

An Electrochemical Mechanism of Corrosion Inhibition by Chromates, Nitrites and Other Oxidants. M. Pourbaix and P. van Rysselberghe. (Corrosion, 1950, vol. 6, Sept., pp. 313–315). The authors report on a theoretical and experimental study of inhibitors based on polarographic investigations. Inhibitors are classed as the surface conversion, adsorption, and diffusion types. The minimum concentration of inhibitor is shown to be that which, for a given oxygen concentration, brings the potential of the metal to a value corresponding to its passivation value. The mechanism described shows that, at inhibitor concentrations insufficient for protection, both the inhibitor and oxygen are consumed in reducing reactions.—R. A. R.

Corrosion Problems in the Railroad Industry. R. McBrian and L. C. Atchison. (Corrosion, 1950, vol. 6, Sept., pp. 286–289). This is a general survey, based on the experience of the Denver and Rio Grande Western Railroad.—O. H. G.

Application of Corrosion-Resisting Materials to Railroad Electrical Construction. H. F. Brown. (Corrosion, 1950, vol. 6, Aug., pp. 268–273). The author reports results of tests extending over more than five years, carried out by a committee of the Association of American Railroads, on the corrosion of ferrous and non-ferrous alloys in smoky atmospheres.—O. H. G.

ANALYSIS

Rapid Photometric Method Assays Chromium in Steel. R. M. Vredenberg and E. A. Sackter. (Canadian Metals, 1950, vol. 13, Feb., pp. 18–19). A spectrographic method for determining chromium in steel, in which the absorption of the stable green chromium–orthophosphoric acid complex is measured, is described. A narrow-band filter combination corrects for interference by nickel. The procedure can be used for a range of 7 to 25% of chromium over which a 1% absolute photometric error produces a relative analysis error of 1·6%.—R. A. R.

Rapid Photometric Determination of Iron in High Temperature Alloys. M. S. Pepi. (Analytical Chemistry, 1950, vol. 22, Apr., pp. 560–561). A rapid method for the photometric determination of iron in alloys for use at high temperature is based on the reaction of the ferrous ion with 1,10-phenanthroline. The sample is dissolved in *aqua regia* and a few drops of hydrofluoric acid, and diluted to 500 ml. A 10-ml. aliquot sample is reduced with hydroxylamine hydrochloride and the orange-coloured complex is formed by adding 1,10-phenanthroline. The reproducibility is good and the average error is $\pm$ 0·02% of the amount present.—R. A. R.

The Estimation of Iron by Dichromate. D. Stockdale. (Analyst, 1950, vol. 75, Mar., pp. 150–155). The relative merits of diphenylamine, diphenylbenzidine, barium diphenylamine sulphonate, ferrous phenanthroline, and potassium ferricyanide as indicators in the estimation of iron by dichromate have been examined. The source of the iron was either ferrous ammonium sulphate or an ore, and the titrations were made in both the presence and the absence of orthophosphoric acid. All these indicators proved efficient when the conditions were suitable. Barium diphenylamine sulphonate was found to be the best, because its colour change is marked and because the end point that it gives is the least affected by the conditions of the titration.

The Determination of Oxygen in Steel by Microscopical Methods. G. Ziliani. (Metallurgia Italiana, 1950, vol. 42, June, pp. 225–229). A microscopical method for the determination of oxygen based on the area of the inclusions and on the analytical determination of the sulphur content in the sample is described. The method requires further improvement before it can be considered sufficiently accurate and readily applicable. Examples are given showing the scope of the method.—M. D. J. B.

New Methods for Determining Phosphorus in Steels. (Steel, 1950, vol. 126, Jan. 30, pp. 46–49, 56, 59). A Geiger-Muller counter for the quantitative measurement of spectral lines has enabled the Ford Motor Co. to make phosphorus determinations at the rate of 30 in an hour. Arc excitation is employed and the 2136·19 Å. phosphorus line is used in the determination.

A recent refinement in the chemical analysis of phosphorus in alloys by J. L. Kassner and M. A. Ozier of the University of Alabama is also described. The time for a complete analysis can be shortened by using a citromolybdate solution and separating the ammonium molybdiphosphate at the boiling point.—A. M. F.

A Spectrographic Investigation of the Distribution of Elements between the Phases of an Alloy. H. Triché. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 31–50). After describing results of tests on the distribution of the impurities lead, aluminium, iron, etc., between the α and β phases of brass, the author proceeds to discuss the spark spectra of cast-iron samples containing nickel (up to 9%) and chromium (up to 5%). The spark, from a Tesla transformer, was played on polished surfaces, and on the same surfaces deeply etched with HCl, but it was found that etching completely altered the iron spectrum of the samples, and tables of the intensity changes in about 500 lines are given, followed by a bibliography of the inter-element interferences recorded in spectra. A theory of the effect of the metallographic structure of the metal on the spectrum is suggested, but interchange of energy between ionized carbon and iron atoms in the spark itself are considered to play a more important part in the changes observed.—E. van S.

Spectrographic Estimation of Carbon in Ordinary Steel and in High-Temperature Alloys (Vitallium). F. Malamand. (Groupement pour l'Avancement des Methodes d'Analyse

Spectrographiques des Produits Métallurgiques, 12th Congress, 1950, pp. 59–67). By the use of a controlled spark with high capacity and minimum self-inductance, the line C 2297 can be used for the estimation of carbon in steel in the range 0·15 to 1%. An aluminium counter-electrode is used sparking 1 mm. from the flat surface of the sample, the spark gap is ionized by an ultra-violet lamp, and the standard samples should be of the same size and shape as the samples analysed. A similar technique is applicable to cobalt–molybdenum–chromium alloys in which carbide formation makes the chemical analysis of carbon unusually difficult. Here a cobalt line at 2286 is used as an internal standard, and satisfactory precision can be obtained in the range 0·1 to 1%. Comparisons with chemical results are given for both materials, and statistics of the precision obtained are quoted.—E. van s.

Progress Report on the Spectrographic Analysis of Steel and [Ni-Cr] Alloys. Monnot. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 85–92). Spark spectra of two metallic electrodes are registered on a quartz spectrograph of medium dispersion for the analysis of steel for silicon, nickel, chromium, wolfram, aluminium, and manganese; the authors state the lines used, the index values, the slope of the calibration line and the reproducibility for each line-pair. The results for silicon, manganese, aluminium, iron, titanium, cobalt, and chromium in the 80/20 nickel–chromium alloy are less precise, and for chromium in the alloy no suitable line-pair has been found. Tables of interfering lines are given and the paper is illustrated by a set of six large enlargements of the portions of the spectrum used.—E. van s.

Application of Direct Reading Analysis to the Analysis of Steel and Distilled Zinc. A. Hans. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 105–112). A direct-reading grating spectrograph of the quantometer type has been tested at the National Metallurgical Research Centre (Liège) on steel, using a device whereby spectra can be recorded photographically while the direct reading is being made. For silicon, chromium, and manganese the standard deviations of replicate tests directly are 0·6 to 0·8% while for recorded spectra of the same source and sample they are about 1·6% for all three elements. Phosphorus in the range 0·02 to 0·09% can be estimated in one minute, including sample preparation, with a standard deviation of the order of 5%; special difficulties have to be overcome for this element. The effect of heat-treatment both on the spectrum lines and on the uniformity of spectra is found to be significant, and has not yet been fully explored.—E. van s.

Estimation of Phosphorus in Steel by a New Direct-Reading Electronic Spectrometer. R. Breckpot. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 99–103). A quartz spectrograph fitted with electron-multiplier cells with quartz envelopes enables the line P 2136 to be used for the estimation of phosphorus in steel. A simple integrating circuit of remarkable stability has been devised, to indicate the output on a milliammeter. Accuracy sufficient for industrial control is obtained, and the spectrograph can easily and rapidly be used for photographic work.—E. van s.

A New Atlas of the Spark Spectrum of Iron. W. Pasveer. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 123–124). The author describes a simple method of preparing a standerd spectrum in the form of enlargements, with a wavelength scale engraved directly on the enlargement with a rudimentary dividing engine fitted to a retouching easel. The spectrum projector and materials used are French, but the principles are widely applicable.—E. van s.

Precise Direct-Reading Analysis of Highly Alloyed Steels. M. F. Hasler. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 113–122). The author describes the quantometer, its associated spectrum source of high reproducibility called the Multisource unit, and the methods used in analysing 18/8 steels for chromium, nickel, manganese, and silicon, and gives some statistics on the precision obtained.

E. van s.

Auxiliary Ionization in Spectrochemical Analysis. E. Sanchez Serrano. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 141–148). The use of radio-active sources, and of flames as means of securing uniform ionization of the spark gap used in spectrochemical analysis has been tried out, and has been shown to give statistically significant improvement in the uniformity of line ratios in the spectra of non-ferrous electrodes.—E. van s.

Spectrographic Study of the Bessemer Converter Flame. R. Breckpot and B. Juchniewicz. (Groupement pour l'Avancement des Methodes d'Analyse Spectrographique des Produits Métallurgiques, 12th Congress, 1950, pp. 137–139). Both visual and ultra-violet spectrographs have been used to survey the spectra of these flames, which only extend to 2950 Å. in the ultra-violet. Besides line spectra of the five alkali metals, those of iron, manganese, calcium, gallium, copper, and silver have been observed, rarely lead and chromium. The temperature rise during dephosphorization can be followed by an extension of the spectral background towards the ultra-violet.—E. van s.

Spectroscopic Determination of Carbon in Cast Irons and Steels. O. V. Blank and N. S. Sventitskii. (Doklady Akademii Nauk S.S.S.R., 1945, vol. 48, No. 4, pp. 269–272). Investigations of two spectrographic procedures for determining carbon in steel are reported, one using the line 4267 Å. and the other the line 2297 Å. In each case the mean probable error of an individual determination was 10%.—R. A. R.

Primary Analytical Standards. A. J. Nutten. (Metallurgia, 1949, vol. 41, Dec., pp. 111–114; 1950, Jan., pp. 175–177, 180; Feb., pp. 237–239; Mar., pp. 287–290). This review deals with most of the substances which have been advanced as primary standards for analysis on the macro or microscale. Their advantages and disadvantages are discussed. They are grouped into three classes, Part I dealing with the alkalimetric and acidimetric, Part II with the oxidimetric, and Part III with the argentometric.—R. A. R.

Determination of Silicon in Iron and Steel by an Absorptiometric Method. (Journal of The Iron and Steel Institute, 1950, vol. 165, Aug., pp. 430–436). This report by the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association deals with two modifications of an absorptiometric method for the determination of silicon, based on the reduction of silico-molybdate to molybdenum blue to cover ranges from 0·05 to 2% and 0 to 0·05% of silicon, respectively. It has been shown that stannous chloride reduction is satisfactory in the higher range, but that for low-silicon contents reduction by ferrous sulphate in the presence of oxalic acid is preferable. Details of the recommended procedures and tables of results are given.

The Estimation of Silicon in 13% Chromium Steels, and Some Remarks on the Perchloric Method of Estimating Chromium in Steels. M. Dodero and R. Rambeaud. (Revue de Métallurgie, Mémoires, 1950, vol. 47, Apr., pp. 315–316). As the silicon in the steel is converted to silica and estimated by a 'difference' method it is necessary that any other insoluble matter accompanying the silica should be as little as possible, hence the need for as complete attack on the steel as possible. In the authors' method the metal is attacked first by hydrochloric acid alone to dissolve silicides not affected in an oxidizing medium, next by nitric acid, and then by perchloric acid to complete the attack and make the silica insoluble; the amount of impurities remaining was small. Another method, using *aqua regia* and perchloric acid, was also fairly satisfactory. This work has a bearing on the solution of chromium steels with perchloric acid; in this method some of the chromium may remain in the residue.

A. E. C.

Contribution to the Determination of Silicon in Steels, in Pig Irons and in Iron Alloys. G. Gavioli and E. Traldi. (Metallurgia Italiana, 1950, vol. 42, Apr., pp. 136–139). An improved gelatine method for the determination of silicon is described and the advantages enumerated. The Weiss method is described, after which the author discusses the determination of silicon in steels containing tungsten, titanium, zirconium, niobium, and tantalum. The determination of silicon is also considered in iron alloys both soluble and insoluble in acid.—M. D. J. B.

Determination of Tin in Highly Alloyed Steels. (Journal of The Iron and Steel Institute, 1950, vol. 165, June, pp. 190–197). This paper is by the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association.

A method of analysis is described which is suitable for the determination of tin in all types of steel. The method is primarily intended to cover the more highly alloyed steels which are outside the scope of the method (issued by the British Standards Institution) for plain and simple alloy steels. The method depends upon solution of the steel in non-oxidizing acid, separation and removal of unattacked complex alloy carbides, followed by precipitation of tin as sulphide, together with molybdenum sulphide as a 'gathering' agent. The filtered sulphide precipitate is dissolved in mineral acid, and after adding the equivalent of 25 mg. of iron, the hydroxides of tin and iron are simultaneously precipitated with ammonia and the determination is completed by applying the conditions of the British Standard method to a solution of the precipitate.

The results show the performance of the method on high-speed tool steels and special types of high chromium–nickel steel containing alloying additions of cobalt, tungsten, molybdenum, titanium, niobium, etc. Various features affecting the quantitative isolation of tin from solutions containing these elements have been examined and are discussed. Attention has also been called to a statement by Scherrer, to the effect that, under certain conditions, tin could not be completely precipitated by hydrogen sulphide. Consideration has been given to an alternative method involving complete solution of carbides, followed by sulphide precipitation from acid citrate solution, but this has marked limitations in the more highly alloyed ranges.

An Improved Method for the Determination of Vanadium in Steel. W. B. Shaw. (Metallurgia, 1950, vol. 41, Feb., pp. 234–236). The author has developed an improved form of Kent Smith's indirect titration method by incorporating a recent modification of Lang and Kurtz's selective reduction of excess permanganate and employing barium diphenylamine sulphonate as internal indicator. In this way rapid and accurate methods of determining vanadium, in both chromium–vanadium and chromium–vanadium–molybdenum –tungsten–cobalt steels, wholly free from end-point difficulties, have been worked out. The procedures are given.—R. A. R.

The Use of Mandelic Acid in the Determination of Zirconium in Steels and Pig Irons. G. Gavioli and E. Traldi. (Metallurgia Italiana, 1950, vol. 42, May, pp. 179–181). A method based on the precipitation of a zirconium complex with mandelic acid and on the final determination of zirconium as oxide is discussed. This method has very definite advantages over those used in laboratories at present, especially when speed and lack of interference from titanium are desired.—M. D. J. B.

The Method Used in the Murex Laboratories for the Determination of Titanium and Aluminium in Ferrotitanium. E. A. Chidley and A. H. Bowes. (Murex Limited Review, 1950, vol. 1, No. 6, pp. 119–120).

What You Should Know about Electrographic Testing. (Steel, 1950, vol. 126, Jan. 23, pp. 56–60, 76). The article describes developments in electrographic methods for identifying metals, alloys, and inclusions. Details of suitable reagents for a limited number of metals are given. The method can also be used for detecting metallic inclusions for which a minimum current density, depending on the inclusion, must be reached, and in the testing of organic surface coatings for porosity and water permeability. Details of a quantitative method of determining porosity are given.—A. M. F.

The Niessner Rapid Process for the Identification of Alloys. F. Lihl. (Werkstoffe und Korrosion, 1950, vol. 1, Feb., pp. 70–74). The Niessner method of identifying alloys is an electrochemical one based on the measurement of the difference in potential between a cylindrical copper electrode and the alloy when the end of the former dips in a few drops of a suitable electrolyte on a plate of the alloy. This paper describes an investigation of the suitability of this test for light alloys and for alloy steels. The test is successful for light alloys and high alloy steels, and in both cases the best electrolyte is 1 *N* KCl with 5% saturated $FeCl_3$ solution. The equipment and procedure are simple and rapid, and can be used in the scrap-metal yard to sort out the high-alloy steels.—R. A. R.

Spectrographic Analysis of Coal and Coal Ash. R. G. Hunter and A. J. W. Headlee. (Analytical Chemistry, 1950, vol. 22, Mar., pp. 441–445). The total-energy method consists of photographing separately on a spectrographic plate the light emitted in a D.C. arc by the complete excitation of 5 mg. of the sample and 5 mg. of a standard of known composition. The optical densities of the lines on this plate are measured, and from these the concentrations of the elements in the sample are calculated. The ash content of coals can thus be determined in a fraction of the time required for customary ashing methods at 740° C. The composition of the mineral matter in the coal in terms of the metallic oxides is simultaneously determined. These data can be used to estimate the fusibility of the ash.—R. A. R.

Incorporating Producer Gas Analysis in Open-Hearth Furnace Statistics. G. Neumann. (Stahl und Eisen, 1950, vol. 70, Feb. 2, pp. 110–111). Equipment is described for the continuous sampling of producer gas from the main supplying the open-hearth furnace. A Horstmann ceramic filter tube is fitted in the top of the main and this is connected by a short small-diameter tube to an electromagnetic diaphragm pump which feeds the gas along a buried gas line to the laboratory where it is analysed.—R. A. R.

Progress Review No. 8 : Sampling, Analysis and Testing of Solid, Liquid and Gaseous Fuels. A. H. Edwards. (Journal of the Institute of Fuel, 1950, vol. 23, May, pp. 152–156). The literature since 1948 reporting investigations which have materially added to the knowledge of the sampling and analysis of fuel (excluding petroleum products used for internal combustion engines) is reviewed. There are 58 references.—R. A. R.

INDUSTRIAL USES AND APPLICATIONS

Reconstruction of 'La Rinascente' in Milan. F. Masi. (Costruzioni Metalliche, 1950, vol. 2, July–Aug., pp. 2–20). [In Italian]. A detailed description is given of a large general stores shop in Milan which was destroyed during the war. The structure offers many interesting features. It is of modern all-welded steelwork and extensive use has been made of broad-flange, Grey-type beams rolled in Luxemburg. For the larger spans, beams were cut longitudinally, a plate inserted and the whole welded into a simple and effective plate girder.—M. D. J. B.

Modern Trends in the Design of High-Tension Pilons. A. Turci. (Costruzioni Metalliche, 1950, vol. 2, Sept.–Oct., pp. 8–15). [In Italian]. This article gives information on the latest types of high-tension pilons recently erected in Switzerland, Italy, and Germany. Design details and characteristics are given; the type and quality of steels are discussed as well as anti-corrosive paints and pilon foundations.—M. D. J. B.

Steel Traversing Pilons for Cable Ropeway. G. Banchieri. (Costruzioni Metalliche, 1949, vol. 1, Jan.–Feb., pp. 21–25). [In Italian]. A description is given of a large traversing pilon carrying a cableway and high-capacity bucket for use in the construction of concrete dams. The cable enables the bucket to discharge at any point across the valley whilst the traversing pilons permit longitudinal motion parallel to the valley. By this means a wide area can be swept by the concreting bucket. The author discusses the bases for calculations, the loads, including dead, live, and wind loads, the tension on the cables, and the effects of moving the pilons. Extensive laboratory tests have been carried out before the erection of the pilons and these are described in detail.—M. D. J. B.

Wire as an Engineering Material. N. B. Bagger. (Materials and Methods, 1950, vol. 31, June, pp. 75–82). This article describes the basic characteristics of wire and the ways in which it can be worked and fabricated. It also gives the principal properties of the many different wire materials, and presents a number of typical applications to illustrate the versatility of wire as an engineering material. The wire materials discussed are: Carbon steel, alloy steel, corrosion-resistant and heat-resistant alloys, copper and copper-base alloys, aluminium and aluminium alloys, and precious metals. P. M. C.

Galvanized Bridge Wire Basic Unit of Americanized Prestressed Concrete Design. B. Birdsall. (Steel, 1950, vol. 126, Apr. 10, pp. 100, 115–118). The basic unit in a system developed by J. A. Roebling's Sons Co. is the use of galvanized bridge strand or bridge rope. These cables are externally anchored and free from bonding to the concrete, thus assumptions regarding shrinkage or plastic flow of the concrete or creep of steel can be checked at any time by measuring the tension in the prestressing member and tension increased if necessary. This galvanized steel can have a designed prestress of 105,000 lb./sq. in.

Reinforced Cast Iron. (Hutnik, 1950, vol. 17, July–Aug., Biuletyn Informacjny Glownego Instytutu Metalurgii i Odlewnictwa, p. 22). [In Polish]. The use of cast iron reinforced by steel bars is briefly discussed.—V. G.

Importance of Design to Tanks and Pressure Vessels. W. Gamans. (Welding Journal, 1950, vol. 29, Jan., pp. 7–16). Code formulæ for the design of pressure vessels are reviewed. A general analysis is given of basic principles behind the relationship of load distribution *v.* stress concentration at abrupt changes of shape in the vessel wall, around opening reinforcements of all sizes, and at the attachment of supports for external loadings in the vessel, or to carry the weight of the vessel itself.—U. E.

Steel Construction in the United States of America. F. Masi. (Costruzioni Metalliche, 1949, vol. 1, Jan.–Feb., pp. 12–18). [In Italian]. This paper describes a visit made by the author to the U.S.A. in order to study the latest developments in steelwork construction. American methods of production, fabrication, and design as well as labour output are examined in relation to Italian practice. Materials handling equipment, portable tools, and recent advances in cutting and welding equipment are described. The general layout and lighting and ventilation of workshops are also dealt with. Structural steelwork design, erection, and costs are reviewed.—M. D. J. B.

Architecture and Structural Steelwork. A. Cavallari Murat. (Costruzioni Metalliche, 1949, vol. 1, Jan.–Feb., pp. 2–11). [In Italian]. The author discusses the fundamentals of aesthetics in architecture and shows how through the ages these have always corresponded to a need of mankind. Beauty in architecture is therefore necessarily functional. The new trends in architecture are examined and in particular the effect the introduction of structural steelwork has had in shaping the modern aesthetics of building.—M. D. J. B.

The Use of Steel in the Conversion of Buildings. U. Rainaldi. (Costruzioni Metalliche, 1949, vol. 1, May–June, pp. 2–9). [In Italian]. A description is given of the complete internal and external reorganization in the general layout of a three-storey building by use of structural steel. The author describes the methods of underpinning and the insertions of steel frames, ties, beams, and stanchions.—M. D. J. B.

Lattice Construction in High-Tensile Steel. G. Tettamanzi. (Costruzioni Metalliche, 1949, vol. 1, July–Aug., pp. 23–24). [In Italian]. The author discusses the technique of high-tensile steel construction and draws attention to the need of taking deformations into account when computing stresses and dimensions. If elastic deformations are calculated and brought into the design, and if care is taken to allow for settlement in the principal members before connecting the seeondary ones, much will have been done to avoid overstressing the structure.
M. D. J. B.

Geometric Characteristics of Expanded Rolled Steel Sections. (Costruzioni Metalliche, 1949, vol. 1, July–Aug., p. 22). A quick method of assessing the moment of resistance and the moment of inertia of expanded sections is described. The sections are ordinary rolled steel joists flame cut and welded in such a manner as to increase their depth. This can be done either by adding a plate or simply by cutting the joist in zig-zag fashion and then transposing the two halves.—M. D. J. B.

Tubular or Rolled Section Construction? P. Lugiato. (Costruzioni Metalliche, 1950, vol. 2, Jan.–Feb., pp. 14–15) [In Italian]. The author discusses the relative merits of tubular and ordinary structural steel construction. The chief advantage of the former is that for equal cross-sections, tubes have a larger radius of inertia and are therefore preferable for compression loading. Moreover, the author suggests that tubular construction is aesthetically more pleasing. The disadvantages are that tubes are rarely of even diameter, that the inner surfaces cannot be readily protected against corrosion and that connections are more complex than with rolled shapes. Slenderness ratios and costs are compared for the two types of section. It would appear that tubular construction is from 80% to 90% more costly than ordinary structural steelwork and that consequently it is unlikely that tubes will supersede rolled steel sections for steel structures.
M. D. J. B.

Structural Steel Columns. G. Spaggiari. (Costruzioni Metalliche, 1949, vol. 1, May–June, pp. 10–20). [In Italian]. A detailed review is given of the various methods of designing stanchions from simple rolled sections to complex fabricated columns. Slenderness ratios are discussed and the general limits of validity for the different types of column are given. The author considers both riveted and welded columns and also the Vierendeel type which has a pleasing appearance. Column bases are briefly considered.—M. D. J. B.

Uniformly Stressed Metal Containers. C. Codegone. (Costruzioni Metalliche, 1949, vol. 1, Nov.–Dec., pp. 11–17). The various methods of designing thin-shell liquid-storage tanks are described. For economy of materials these are uniformly stressed structures and of ovoid shape. Examples are given of North American containers of capacities varying between 12,500 and 100,000 barrels and designed to stand internal pressures from 15 lb./sq. in. to 250 lb./sq. in. If the spherical container is filled with a liquid, the hydrostatic pressure will set up unequal stresses in the skin due to deformations. These cannot be neglected, and the author describes an elegant mathematical solution due to Prof. Colonnetti for the stress analysis of these spheroid containers.—M. D. J. B.

Oxygen in Industry and Its Applications. N. L. G. Lingwood and R. E. Dore. (Manchester Association of Engineers, Nov., 1949, Advance Copy). The industrial uses of oxygen are briefly described with many illustrations. In addition to welding, cutting, and deseaming or scarfing, the more unusual processes described are flame-hardening a rotating shaft, and shaping tube ends by flame-spinning.—R. A. R.

HISTORICAL

Some Inventions of Sir Henry Bessemer. G. Baker. (Journal of the Junior Institution of Engineers, 1950, vol. 60, Sept., pp. 345–377). Brief accounts are given of many of the inventions of Henry Bessemer. The versatile nature of his activities is seen from the following selection of the many inventions described: Bronze-coated medallions; dies with provision for changing the date, for stamping documents; sawing plumbago with less waste; a machine for setting type; embossing Utrecht velvet; making bronze powder; a press for sugar cane; glass furnace and rolls for making sheet glass; and a Channel steamer in which was a saloon, which could be oscillated so as to keep it level while the ship rolled. Early experiments with the Bessemer converter are described with several drawings of plant and casting arrangements.—R. A. R.

The Old Wortley Ironworks. C. R. Andrews. (British Steelmaker, 1950, vol. 16, Jan., pp. 12–14; Feb., pp. 66–69; Mar., pp. 112–115; Apr., pp. 168–170; May, pp. 231–235; July, pp. 358–361). The author in the first part of the paper describes the old Wortley Iron Works near Sheffield as they were about 50 years ago. In the second part the early history of ironmaking and forging at this site is traced to show that the first ironworkers there were probably monks in the second half of the XIIth century. In the third part the history of the works is brought up to the XVIIth century at the beginning of which the old bloomery process probably gradually died out. Evidence from documents is cited in the fourth part to show that ironstone was smelted here from an "early period till after the reign of Charles I, when the bloomery on the bank of the Don was pulled down and a forge erected." The works prospered during the latter half of the XVIIth century. The fifth part covers the history of the works in the XVIIIth century when activities greatly expanded. A description and drawing of a Cockshutt rolling mill with 6-in. rolls are given. In the final part the story is brought up to 1929 when the works fell into disuse.—R. A. R.

Two Metallurgical Jubilees. L. Jeníček. (Hutnické Listy, 1950, vol. 5, Aug., pp. 317–320). [In Czech]. The author writes of the lives and work of Sydney Gilchrist Thomas and Henry Le Chatelier commemorating the centenary of their birthdays and their contribution to metallurgical progress, with particular reference to their influence on the development of the metallurgical industry in Czechoslovakia.—E. G.

The Centenary of the Birth of Sidney Gilchrist Thomas. H. Dickmann. (Stahl und Eisen, 1950, vol. 70, Apr. 13, pp. 301–303). The life and work of Thomas is briefly outlined. Portions of the patent application in Thomas' own handwriting, for the basic-lined converter, are reproduced in facsimile.—J. P.

The Introduction of the Basic-Bessemer Process in Luxemburg. N. Mousel. (Revue Technique Luxembourgeoise, 1950, vol. 42, Apr.–June, pp. 79–88). An historical account of the development of the process invented by Thomas and introduced into Luxemburg in 1882 is given. The tremendous effect it has had on the steel industry is discussed.
B. G. B.

Czech Historical Art Castings. (Hutnické Listy, 1950, vol. 5, Jan.–June, Supplements). Six supplements on art paper show examples of castings in Czechoslovakia, most of which are of historic interest.—R. A. R.

Metallurgy in Africa. P. L. Breutz. (Iscor News, 1950, vol. 15, Sept., pp. 771–775, 781). The manufacture of iron by native Africans is surveyed. An intensive iron industry which had developed from the VIIIth century A.D. was still flourishing in the days of the Portuguese explorers.

In marked contrast to the honoured status enjoyed by smiths among the Bantu and Sudanese, metal workers are generally despised amongst the Hamitic peoples of the north and north-east who look down upon physical work of any kind.

Early brands of iron were highly phosphoric and brittle. The ores were first roasted in the open air to oxidize the sulphur to sulphurous acid. The iron was cooled very slowly in African smelting, a crust of graphite and iron carbide being precipitated. The African usually produced iron more suitable for forging than for casting. The temperature reached in native furnaces was not high enough to effect proper smelting of the ore which merely formed a spongy mass, gradually losing the excess carbon and becoming an amorphous, cindery iron lump. In some regions, *e.g.*, Togoland, furnaces are 7 to 10 ft. high so as to cause a draught through the stack without the use of bellows.

Most 'large' African furnaces are based on the principles applied in Europe up to the XVIIIth century. They are built of clay and usually do not survive more than one or two smeltings.—R. S.

The Rise of the English Iron Industry between 1550 and 1660. H. R. Schubert. (Journal of The Iron and Steel Institute, 1950, vol. 165, July, p. 278). A list, compiled in 1559–60, of wares imported into London showed the annual import of iron combined with steel and iron wares to have a value of £38,417, but a century later a traveller wrote that iron had become an article of export.—R. A. R.

The Work of the Czech Physicist Čeněk Strouhal Concerning Metallurgy. L. Jeníček. (Hutnické Listy, 1950, vol. 5, Apr., pp. 138–148). [In Czech]. On the occasion of the hundredth birthday of Čeněk Strouhal the author reviews his work and that of Baru, written about 70 years ago, on the physical properties of alloys, particularly steel. The influence of their work in metallography is assessed and it is shown that some of the results obtained by Strouhal and Baru are still useful.

E. G.

Bibliography of the Scientific Papers of the Czech Scientist Čeněk Strouhal. L. Jeníček and J. Koutecký. (Hutnické Listy, 1950, vol. 4, Apr., p. 137). [In Czech]. This bibliography contains a list of all the scientific papers written by the Czech scientist Čeněk Strouhal who was born 100 years ago.—E. G.

Some Problems of Hardness Testing—Review of the Historical Developments of Hardness Testing. L. Jeníček. (Hutnické Listy, 1950, vol. 5, Apr., pp. 163–167). [In Czech]. The author investigates the historical development of hardness measurement and shows that many of the methods developed to fill the needs of specific practical work are no longer justified. There is still no uniform conception of what hardness is, in spite of 250 years of research. In many cases the conversion of the hardness values obtained by one method to those of another is based on purely empirical conversion curves. The various steps in the development of hardness measurement from 1722 to 1947 are enumerated in chronological order. The bibliography contains 55 references.—E. G.

ECONOMICS AND STATISTICS

The Development of the Iron and Steel Industry in the First Year of the Plan. H. Grabner. (Die Technik, 1950, vol. 5, Feb., pp. 57–58). Production data for pig iron, steel ingots, sections, and plates in the Eastern Zone of Germany showing the percentage increases in 1947, 1948, and 1949 are given.—R. A. R.

Raw Materials of the Iron and Steel Industry. A. K. Osborne. (Purchasing Officers' Association, Raw Material Survey Series, 1950, No. 1). In this 31-page booklet the author deals briefly, and in alphabetical order, with the wide range of raw materials of the iron and steel industry. Indications of the sources, availability, and consumption of the various materials with a very brief outline of their uses and methods of production are given.—R. A. R.

Developments in the Iron and Steel Industry during 1949. I. E. Madsen. (Iron and Steel Engineer, 1950, vol. 27, Jan., pp. 93–118). The author describes the technical innovations introduced in 1949 which have contributed to make this year the third largest steel-producing year in history. Statistical data on pig iron, steels, and raw materials are given. New products, new markets, production costs, freight charges, and general economics in the industry are discussed. Expansion of the iron and steel industry in the U.S.A. and in Europe, notably in Great Britain, France, Belgium, and Italy is reviewed. The author describes the latest trends in blast-furnace and coke-plant practice in relation to available materials, new coking coals, and the new Chilean and Venezuelan ore deposits. Information is given on a new basic side-blown converter, the use of oxygen, all basic open-hearth furnaces, electric furnaces, and on spectrographic testing equipment. New mills and techniques are described, including a 66-in. 4-high reversing mill, high-speed cold reduction, rod mills, tube mills, gauging equipment, and wire-drawing equipment for stainless and alloy steels. Information is also given on finishing processes, fuels, reheating furnaces, materials handling, and on mechanical and electrical developments.—M. D. J. B.

British Steel—Some Post-War Developments. (Metallurgia, 1950, vol. 41, Feb., pp. 181–190). An illustrated review is presented of extensions, improvements, and developments at many of the iron and steel works in Great Britain.—R. A. R.

The Niagara Hudson Power System and Its Relation to the Steel Industry. R. T. Henrys. (Iron and Steel Engineer, 1950, vol. 27, Feb., pp. 60–62). This article gives information concerning the organization of the Niagara Hudson Power system. The principal operating companies, capacities, population, and industries served are given. Brief details are also given of the steam and hydroelectric power plants, and of the methods of interchange under emergency conditions between the various divisions of the system.—M. D. J. B.

MISCELLANEOUS

The Problems of Materials Handling in the Steel Industry. W. G. Nichol and W. N. Flanagan. (American Iron and Steel Institute, May, 1950, Preprint). This 127-page handbook describes many problems relating to the movement of materials in steelworks and how they have been solved. The materials and departments dealt with are coal, materials for the blast-furnaces, Bessemer converters, open-hearth furnaces, electric furnaces, soaking pits, and rolling mills. There are 98 illustrations.—R. A. R.

Materials Handling in Industry. (Anglo-American Council on Productivity, 1950, May, Productivity Report). This is a report by a British team which recently visited the United States to study materials handling, on what the team saw, and the conclusions they arrived at.—R. A. R.

Relationship of Material Handling to Production. J. S. Freese and F. C. Wier. (Iron and Steel Engineer, 1950, vol. 27, Apr., pp. 51–56). A new method of production planning introduced into the Steel and Tube Division of the Timken Roller Bearing Co. is described. The authors show the advantages which can be derived from production control in the clerical departments and how this control, when coupled with improved materials handling, can relieve congestion by ensuring that materials are kept flowing through the various departments. Specially designed trucks greatly facilitate the storing of materials in the open. Stress is laid on the advantages gained by introducing very high-frequency two-way radio communication between the truck driver and the materials dispatcher. The system ensures full utilization of the trucks, provides the utmost flexibility, and eliminates all possible confusion in the transmission of orders.—M. D. J. B.

The " Westphalian Raft " As a New Carrier for Aggregates. E. Westphal. (Stahl und Eisen, 1950, vol. 70, Feb. 2, pp. 97–109). To reduce the cost of transport of ores, coal, coke, sand, and similar materials on the German canals an entirely new form of barge called the ' cargo tube ' (' *Lastrohr* ') has been devised, and is already in use. The maximum size is 3 m. in dia. by 24 m. long with an open top, three bulkheads, stringers, but no ribs. Their shape makes them self-trimming and they are unloaded by being lifted bodily and tipped. The ends are flat, and a raft of 24 ' tubes ' consisting of eight

articulated sets of three abreast, or six sets four abreast, can easily be towed by a tug. The economic advantages of this new system of water transport are explained with many diagrams.—R. A. R.

Protection of Steel in Transit. A. H. Andrews. (American Iron and Steel Institute, May, 1950, Preprint). Various stages in the movement of steel products from the point of production to point of consumption are described with special reference to methods of loading pipes, sheets, and bars on railway wagons so as to prevent damage.—R. A. R.

The Supply and Distribution of Water to Iron and Steel Works. J. L. Daniel. (Journal of The Iron and Steel Institute, 1950, vol. 165, Aug., pp. 437–453). The paper deals with the supply and distribution of water at the Corby Works of Messrs. Stewarts and Lloyds, Ltd. Brief descriptions are given of the initial problems of water supplies from various sources, and of subsequent methods of distribution within the works, including supplies to tube works and a cold-strip mill.

Heating and Ventilation in the Iron and Steel Industry. F. R. L. White. (Journal of The Iron and Steel Institute, 1950, vol. 165, June, pp. 221–226). Environment has a very great influence upon the general bearing and well-being of operatives. Their productive output is enhanced if they work in healthier conditions. With a proper appreciation of the heat-producing and heat-dissipating mechanism of the human body, the problems of heating and ventilation may be regarded as constituting the maintenance of a proper thermal balance between human beings and their surroundings. It is unnecessary to provide heat for a human body; the body does that for itself. The problem is to regulate the flow of surplus heat from the human body so that it may maintain its normal temperature associated with a healthy bodily condition. The feeling of comfort is not dependent upon temperature alone. Air movement, humidity, and freedom from contamination are all vital and inseparable factors.

In the iron and steel industry it is impossible to generalize upon the subject of heating and ventilation. Each section of the industry and each sub-division of any particular undertaking has its own individual problems, and in the majority of cases each has to be studied during production operations in order to arrive at a suitable solution. Various practical applications are suggested, and these may be separately, or in some cases jointly, adopted to provide suitable environmental conditions.

Much headway has been made in the use of mechanical aids to shift the burden from the operative, especially where excesses of temperature are to be met. Nevertheless, it is to be hoped that future research into production methods will result in greater relief from many of the present excessive conditions.

Instrumentation in Iron and Steel Practice with Reference to Automatic Control. W. B. Wright and J. W. Muir. (West of Scotland Iron and Steel Institute, Feb., 1950, Preprint). The paper deals with the principle, application, and accuracy to be expected of a number of industrial instruments which serve as useful aids in the production of iron and steel. The subjects discussed include flow measurement, temperature measurement, CO_2 measurement, and the application of automatic control. The basic principle of a specific controller is described, and an attempt is made to show the ease with which this basic principle, with slight modification, can be adapted for widely differing forms of control application. Finally, reference is made to the various types of automatic control action.

The Application of Model Tests for Solving Problems of Flow. W. Barth. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Feb. 11, pp. 105–110). Model tests do not as a rule fulfil all the conditions of full-scale plant. In this paper errors which can arise in interpreting the results of such tests are discussed, and models used to study flow in wind tunnels, gas cleaners, and open-hearth furnaces are described.—R. A. R.

Speed, Steam Pressure, Temperature and Voltage as Important Quantities in Technical Advancement. F. Bauer. (Stahl und Eisen, 1950, vol. 70, Mar. 2, pp. 166–174). Data are presented showing the increases in speed of processes, pressure and temperature at which steam is used, electricity consumption, and transmission voltage. In many cases these are plotted against time over long periods. The trends are discussed with a view to indicating whether there is a prospect of maximum values being reached in a short or long time.

Quality Control Lowers Costs, Boosts Production. N. G. Meagley. (Iron Age, 1950, vol. 165, Apr. 27, pp. 91–94). Quality control of pressing, forging, machining, and painting at Willys-Overland Motors Inc. by means of statistical control charts is described. These may show the percentage rejected at each inspection, defects in a fixed sample size, or actual dimensional variations of a part.—A. M. F.

The Application of Statistical Methods to Quality Control. A. Palazzi. (Metallurgia Italiana, 1950, vol. 42, May, pp. 153–166). In recent years mathematical statistics have supplied graphical methods for analysing production rates and quality control. By these methods it is possible to obtain an unbiased picture of the stability or variations of phenomena with time. The methods of quality control are of considerable technical and economic value and can be applied to all technical fields. After examining the fundamentals of statistical quality control and describing the principles of control charts, the author deals with a number of practical examples taken from industry.—M. D. J. B.

Examples of Structural Steel Design to Conform with the Requirements of British Standard 449 : 1948. V. H. Lawton. (British Constructional Steelwork Association, 1950, Publication No. 1). The author selects a few of the more common problems in the design of steel-framed buildings, and offers suggestions for their practical solution to conform with the requirements of the new Standard.—R. A. R.

A New Type of Separator. B. Bianchi. (Metallurgia Italiana, 1950, vol. 42, Apr., pp. 128–132). A new dust separator, specially designed for production control, is described. The apparatus is simple and practical, and is capable of separating dust particles and classifying these according to diameters. The granulometric distribution curve of the dust can be read without resorting to complex calculations. The granulometer, which is evolved from basic sedimentation apparatus, makes use of the well-known Stokes formula. A number of graphs obtained from actual tests illustrates the application of the formula and the scope of the apparatus.—M. D. J. B.

Design of a Large Vacuum Valve : Its Application to an Electric Furnace. W. F. Atkins and G. C. H. Jenkins. (Metallurgia, 1950, vol. 41, Mar., pp. 266–267). The last operation in a process developed at the National Physical Laboratory for producing high-purity iron in quantities of 25 lb. is the deoxidation of the molten metal by hydrogen in a high-frequency furnace inside a large vacuum-tight tank. To enable the tank to be isolated from the pumps it was necessary to fit a valve in the 8-in. pipe to the pumps. This valve had to be completely vacuum-tight and capable of being opened gradually over the whole range from fully closed to fully opened. Details of the valve constructed for this purpose, and its operation are given.—R. A. R.

Continuous Capacity of Copper Wire for Tie Lines. (Iron and Steel Engineer, 1950, vol. 27, Feb., pp. 94–98). The author describes the problem of transmitting power between two steel mills 13 miles apart. Considerable doubt existed as to whether the existing line would carry the increased load, and a number of solutions were put forward but rejected on the basis of cost. A careful study of the problem taking the effects of ambient temperature, speed of wind, annealing of copper, effect of sun and fault current shows that the existing line is adequate to carry the extra load.—M. D. J. B.

BOOK NOTICES

CAZAUD, R. "*Métallurgie.*" 64e Edition. 16mo.. pp. xxiv + 318 + xlvi. Paris, 1948. Dunod. (Price 350 fr.)

The most recent edition of this popular pocket-size handbook contains a large amount of useful and accurate information especially for the technician.

The first part deals with the methods of testing metals, and covers, with full practical details, tensile, hardness, impact, bending, creep, fatigue, and corrosion tests. In addition the techniques of preparing specimens for micro- and macrographic examination are described.

Part two covers thermochemical and thermal treatments. By the former is meant such processes as gaseous and electrolytic cementation, nitration, etc. The heat-treatment of both light alloys and steels is well treated and includes descriptions of modern methods of quenching based on the **S**-curve.

Part three is a brief survey of the metallurgy of iron while part four deals with the other elements and contains separate sections on the precious metals and on those of special importance, *e.g.*, chromium, molybdenum, tungsten.

The book ends with an account of the factors affecting corrosion and methods of prevention by special alloys or by plating.—A. GRIEVE

GLAZUNOV, A. "*Métallographie, les Diagrammes d'Équilibre par Questions et Réponses.*" 8vo, pp. 240, 425 figures. Paris, 1951. Dunod. (Price 1280 fr.)

This book, giving a valuable introduction to the subject, is intended for students and industrial technicians. Its Socratic method of question and answer, combined with a detailed examination of the phase regions of a large number of binary diagrams, makes for clarity at the expense of conciseness, but with such a subject this is probably a good fault. The first part deals with definitions, the phase law, and the mechanism of solidification and recrystallization.

The remainder of the book studies binary diagrams of increasing complexity ranging from simple solution to systems containing 'Daltonide' or 'Berthollide' phases.

There is also a short chapter on the variation of physical properties with composition and structure of the alloy.

A. GRIEVE

GUMBEL, W. and K. POTTER. "*The Iron and Steel Act, 1949.*" 8vo, pp. xxxii + 152. London, 1951; Butterworth and Co. (Publishers) Ltd. (Price 25*s.*)

This book, reprinted from Butterworth's well-known "Annotated Legislation Service," contains the Iron and Steel Act, 1949, with an introduction and annotations. The introduction contains a brief history of the arrangement of the industry, the origin and functions of the British Iron and Steel Federation, the war-time Iron and Steel Control, and the post-war Iron and Steel Board; it deals with the passage of the Bill through Parliament, and the general effect of the Act on the iron and steel industry, and concludes with a summary of the provisions of the Act. In the main body of the book, the Act is printed section by section, with notes following, each of which first summarizes the general effect of the section, and then explains particular phrases or passages, sometimes in the light of other parts of the Act, sometimes by reference to other legislation. The value of these notes can be seen from one example: A passage of 140 words headed "Subsidy in Respect of Imported Materials," and indicating that where the cost of imported materials exceeds selling prices of similar materials in this country, the Treasury may authorize a subsidy, requires, for the full clearing up of any ambiguity and the explanation of the constitutional position, a general note of 240 words and detailed explanation of nine phrases totalling 43 words of the original, none of which appear particularly ambiguous to the ordinary reader. This wealth of notes, made by two barristers of considerable experience, will make this book very valuable to those concerned in any way with the affairs of a company affected by the Iron and Steel Act.—J. P. S.

HANDISYDE, C. C. "*Building Materials: Science and Practice.*" 8vo, pp. 336. London, 1950. Architectural Press. (Price 25*s.*).

This book was compiled at the request of the Text and Reference Books Committee of the Royal Institute of British Architects to provide a work for students which would take into account recent research on building materials old and new. The author has had research experience at the Building Research Station, practical day-to-day experience as an architect, and has lectured on "Building Materials" at an important architectural school. This broad experience has enabled him to produce a most interesting book; naturally, most of the materials dealt with are of non-metallic nature, brick, stone, concrete, slate, fibre board, etc., but his treatment should hold the attention of those metallurgists whose interest in buildings is confined to looking at and living in them. He has provided one chapter on metals, confining himself to descriptions of the production, working, and use of the commoner metals, iron and steel, copper alloys, light alloys, lead, and zinc, and considering them less as structural materials than as such non-structural components as windows and doors, handrails, ironmongery, roof finishes, and plumbing. His description, however, is lucid and accurate, and the architectural student should derive as much benefit from the study of this chapter as the metallurgist may from that of the other materials with which the author deals.—J. P. S.

HILL, R. "*The Mathematical Theory of Plasticity.*" 8vo, pp. ix + 356. The Oxford Science Series. Oxford, 1950: Clarendon Press. (Price 35*s.*)

'Mathematical' is the operative word in the title of this book, which is concerned with outlining a subject in applied mathematics. The task of this theory is to posit mathematical relations between stress and strain in permanently deformed solids, which agree as closely as practicable with observations, and to develop techniques for calculating non-uniform distributions of stress and strain in bodies plastically distorted. Since at present the theory is related specifically to metals and finds its principal application in technology and engineering, the book deserves especial notice in this *Journal*.

The origins of the theory are to be found in the writings, some 80 years ago, of St. Venant and other illustrious contributors to the theory of elasticity, to which it is closely related. Unlike the latter, however, it is a still immature science; little progress took place before 1920, and it is really only in the last ten years that great advances have been made in it. Between the two wars the theory owed most of its developments to German mathematicians. Today there are several flourishing schools of 'plasticians,' notably in America and Russia; Dr. Hill is the leading exponent in this country.

Whilst numerous papers have been published on this subject, some of them in this *Journal*, Dr. Hill's is only the fourth book to deal with plasticity, and the first one in English to be devoted exclusively to the mathematics of it. The task of writing an authoritative and comprehensive first text on a new and rapidly expanding science is a difficult and highly responsible one. Dr. Hill has done this job most conscientiously and, in spite of the difficulties of the subject, in a style that is, without any sacrifice of precision, eminently readable.

The book opens with an introductory chapter in which the subject is defined, its history outlined, and its physical background given with reference to metals. The second and third chapters are on the mathematical foundations of the theory and its basic theorems, and are followed by two chapters on problems for which analytical solutions are known and in which either the entire body is in the plastic state, or in which elastic and plastic regions exist side by side, the plastic and elastic strains being of comparable magnitudes. The next four chapters are devoted to plane strain theory and its applications; a further two chapters deal with problems of axial symmetry and miscellaneous topics; and the final one is concerned with the theory for an anisotropic metal. Four mathematical appendices, a comprehensive author index, and a brief subject index conclude the book.

The *pièce de résistance* of the book, both metaphorically and literally, is to be found in the second, third, and sixth chapters. To the technologist, however, chapters seven to eleven are of greatest interest, and, incidentally, the easiest to follow. They are concerned with technological forming processes, such as the rolling of strip, drawing of wire, extrusion of rods and tubes, piercing, and deep drawing. These processes are analysed so as to determine the external loads, the power consumption, and the strain hardening due to non-uniform deformation. The reader will also find several standard mechanical tests examined in the light of the theory with a view to assessing their physical significance. It is in the field of problems of technological application that Dr. Hill himself has contributed a large share of recent advances, particularly in the critique of earlier solutions which do not satisfy conditions imposed by the displacement of the metal. In these studies he proves not only his mathematical ability but also displays a nice sense of 'applicable' mathematics in using approxi-

mations and simplifications whenever they are justified by the practical value of the results.

Dr. Hill writes in the preface that his especial concern has been to provide data for research workers and to attract engineers and applied mathematicians to what is a young science and one that will reward study. The first aim is well met and the book is an indispensable text for everyone concerned with the fundamentals of metal working. In regard to the second aim, unsolved problems are clearly indicated, and there are many suggestions for theoretical and experimental investigations.

J. G. WISTREICH

KRAUSKOPF, W. "*Metall- und Legierungsregister.*" Sm. 8vo, pp. 144. Munich, 1950: Carl Hanser Verlag. (Price DM 7.40)

This list of about 1800 alloys, alphabetically arranged, gives, in most cases, the composition, and in many, the application. Where the manufacturer is German, his name and address are usually given in full; where the alloy is of foreign origin this is generally indicated, though it is seldom that the actual manufacturer of a foreign proprietary alloy is mentioned. For the makers of Dowmetal, Hastelloy, Monel Metal, and Staybrite, for instance, the German reader will search in vain. The foreign reader, on the other hand, will certainly discover a great many alloys of familiar composition under names which may be strange to him: he will also find the names he is accustomed to most curiously spelt, *e.g.*, "Though-Kupfer," for "tough-pitch copper" and "Birmighamneusilber" for "nickel-silver." The author's inability, or unwillingness, to find the correct spelling of non-German names has enabled him, however, to fill his pages with a satisfying number of cross references. These could have been better replaced by some particulars, melting points for instance, of the 'metals,' which make no other appearance in the book except on the title page and in a list of chemical symbols.—J. P. S.

SANDELL, E. B. "*Colorimetric Determination of Traces of Metals.*" Second edition. 8vo, pp. xix + 673. New York, 1950: Interscience Publishers, Inc.; London: Interscience Publishers, Ltd. (Price 72*s.*)

The author of this book, Professor Sandell, defines a trace constituent of a sample as one occurring to the extent of 0·01% or less, and there can be but few analysts who determine such small amounts as a routine matter. When presented with such a problem the analyst's choice of a method frequently falls on colorimetry. Colorimetric methods can give reasonable accuracy with the simplest of apparatus, such as Nessler tubes; even a spectrophotometer, which is advisable for most colorimetry, is far less expensive than a spectrograph, its only rival for sensitivity.

The many new colorimetric methods recently published in the literature have caused Professor Sandell to make numerous additions to the methods presented in the first edition of this book, but the scope of this second edition remains the same. The aim of the author has been to present a limited number of methods which appear to him to be best suited for the determination of small amounts of metals. No one reagent is necessarily the best for the determination of an element in all kinds of materials, and consequently two or three methods for one metal are often described.

The first part of the book commences with a general chapter on trace analysis, and this is followed by a chapter on methods for the separation and isolation of traces of substances. The third chapter deals with colorimetry and spectrophotometry in trace analysis, and the last chapter of this part of the book describes the characteristics of a number of general colorimetric reagents.

The second, and major, part of the book gives procedures for the determination of traces of 45 metals. The contents of the chapter on chromium illustrate well the high standard of this book. Separations of chromium, subdivided into precipitation and extraction methods, are dealt with in two pages; then come two pages with a general discussion on the determination of chromium by means of its conversion to chromate, and four pages on the determination of chromium by means of its complex with diphenylcarbazide. Other methods of determination are briefly discussed. The last section of the chapter gives, with full practical details, the application of the previously described methods to the determination of chromium in silicate rocks, iron ore, iron and steel, and biological materials. Many references are given.

This book would be a useful addition to the library of any analytical laboratory.

The standard of printing and binding is high.

J. B. BOOKEY

WIRTSCHAFTSVEREINIGUNG EISEN- UND STAHLINDUSTRIE, DÜSSELDORF. "*Statistisches Jahrbuch für die Eisen- und Stahlindustrie.*" 8vo, pp. x + 219. Düsseldorf, 1950: Verlag Stahleisen m.b.H.

Production by quantity and value of iron ore, pig iron, steel, and many steel products are presented in tables, according to country of origin; where countries are not producers but importers, the source of imports is given. The years taken for purposes of comparison are 1936 (or 1938) 1947, 1948, and 1949. This little book, therefore, contains much that enables one to ascertain present trends in iron and steel production and compare them with pre-war conditions.—J. P. S.

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AMERICAN SOCIETY FOR TESTING MATERIALS. "1950 *Supplement to Book of A.S.T.M. Standards Including Tentatives. Part 2. Non-Ferrous Metals.*" 8vo, pp. x + 223. Philadelphia, 1950: The Society.

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BRITISH STANDARDS INSTITUTION. B.S. 781: 1950. "*Wrought Iron Chain Slings and Rings, Links Alternative to Rings, Egg Links and Intermediate Links.* 8vo, pp. 1–48. London: The Institution. (Price 6*s.*)

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VIGOUREUX, P. "*Ultrasonics.*" Pp. vi + 163. London, 1950: Chapman and Hall, Ltd. (Price 25*s.*)

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